The EIC and Electroweak physics

Thomas Burton

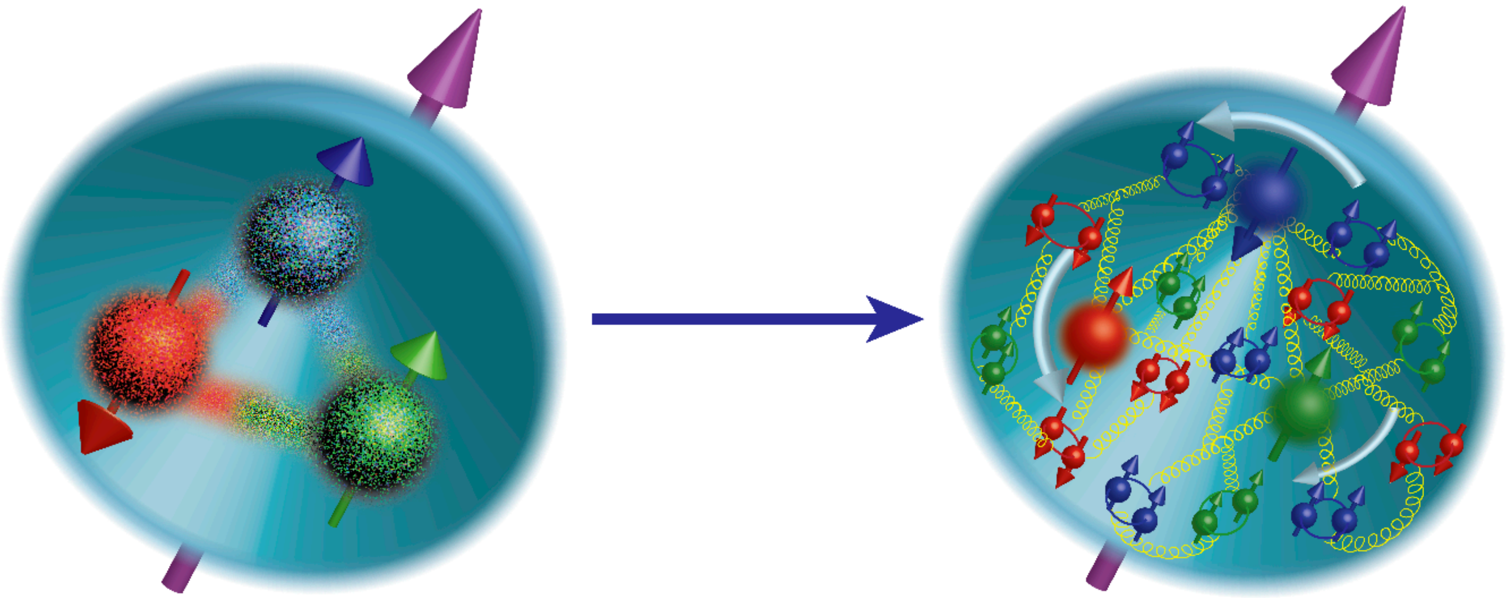
PAVI14

Overview

- TBD

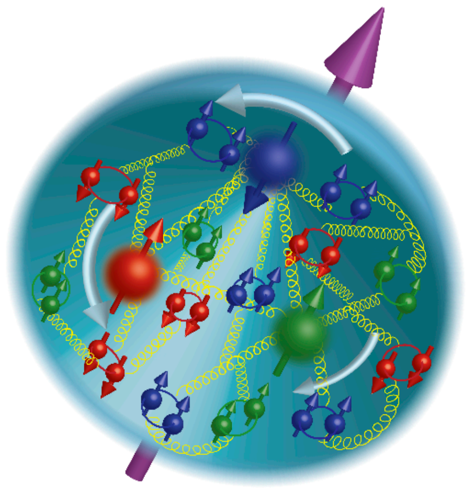
What is the EIC?

Electron-**I**on **C**ollider

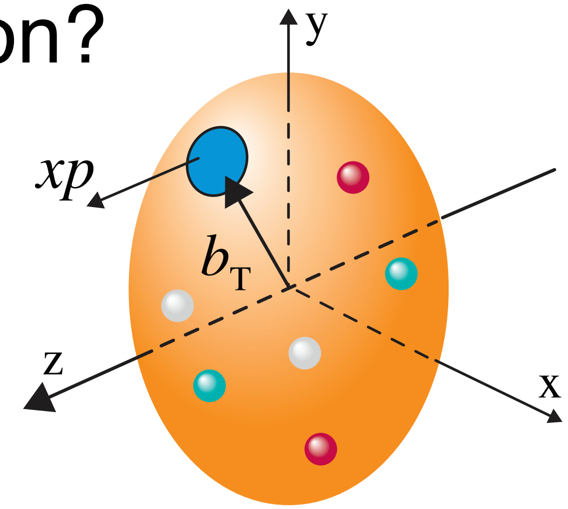


"A next generation facility with unique capabilities in nuclear structure and dynamics, exploring the next QCD frontier."

Why do we want an EIC?

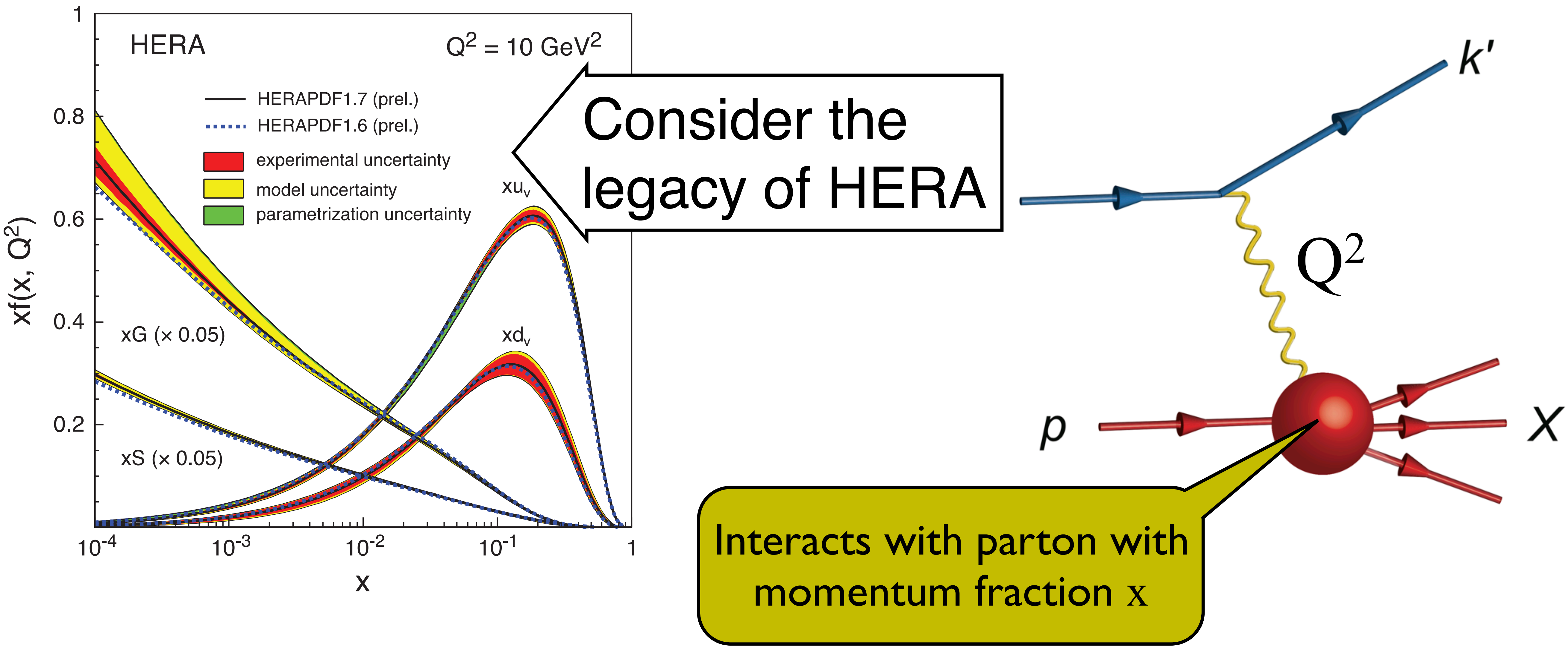


- Much we still don't understand about **QCD**
  - Role of sea quarks and gluons in **spin**?
  - How does parton **motion** contribute to nucleon
  - How are quarks and gluons **distributed**?
  - What happens to gluons at **high densities**?
  - Is there **nuclear modification** of gluon distribution?
  - Interactions of partons with **nuclear matter**?
  - **Formation of hadrons** from partons?



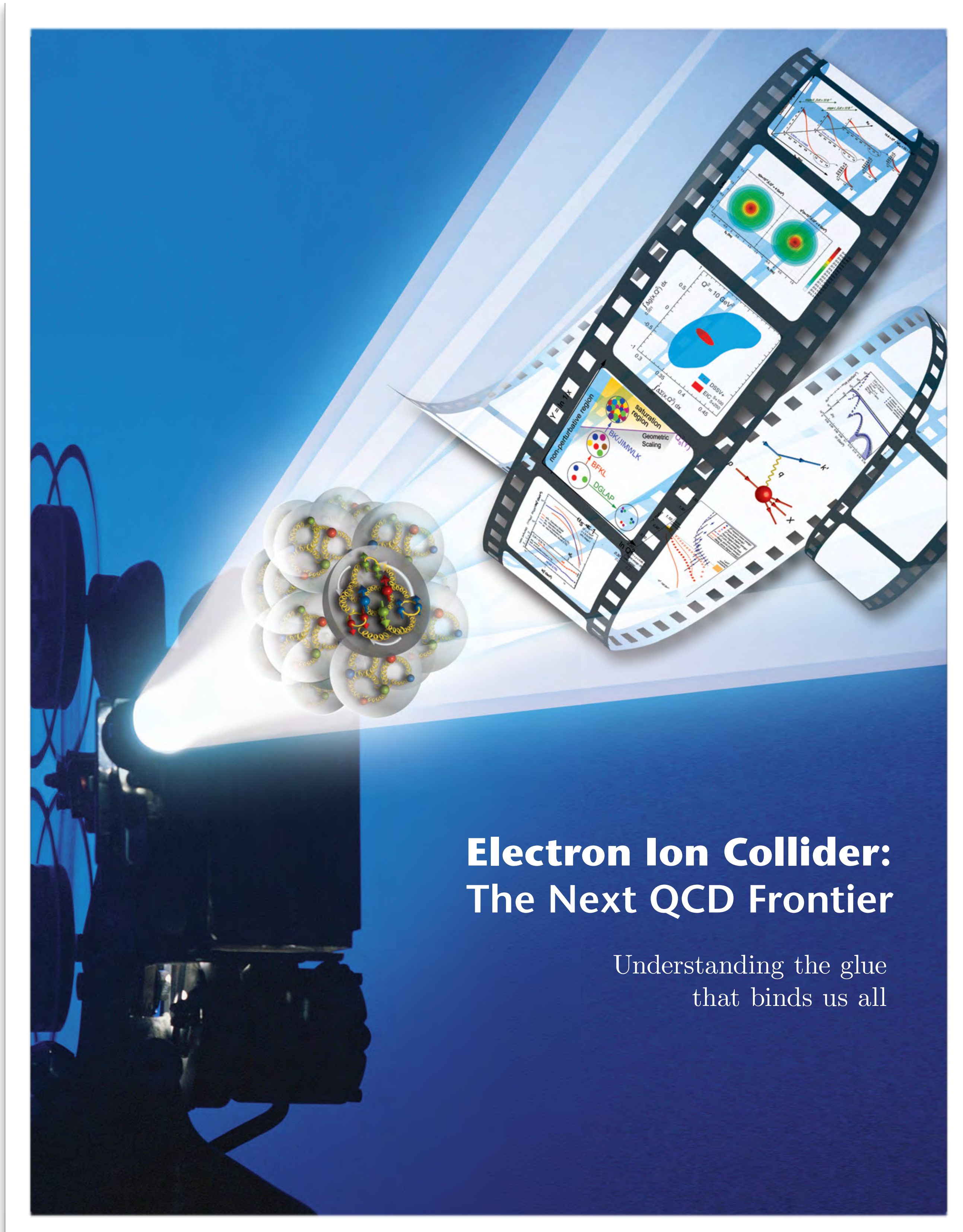
The EIC has a broad programme to answer these questions

Why use electrons?



- **Precision** - direct access to parton-level
- **Control** - "dial" x-Q^2 via electron E, θ
- **Cleanliness** - no fragments from another beam

What is the key physics?



Imaging

Nuclear environment

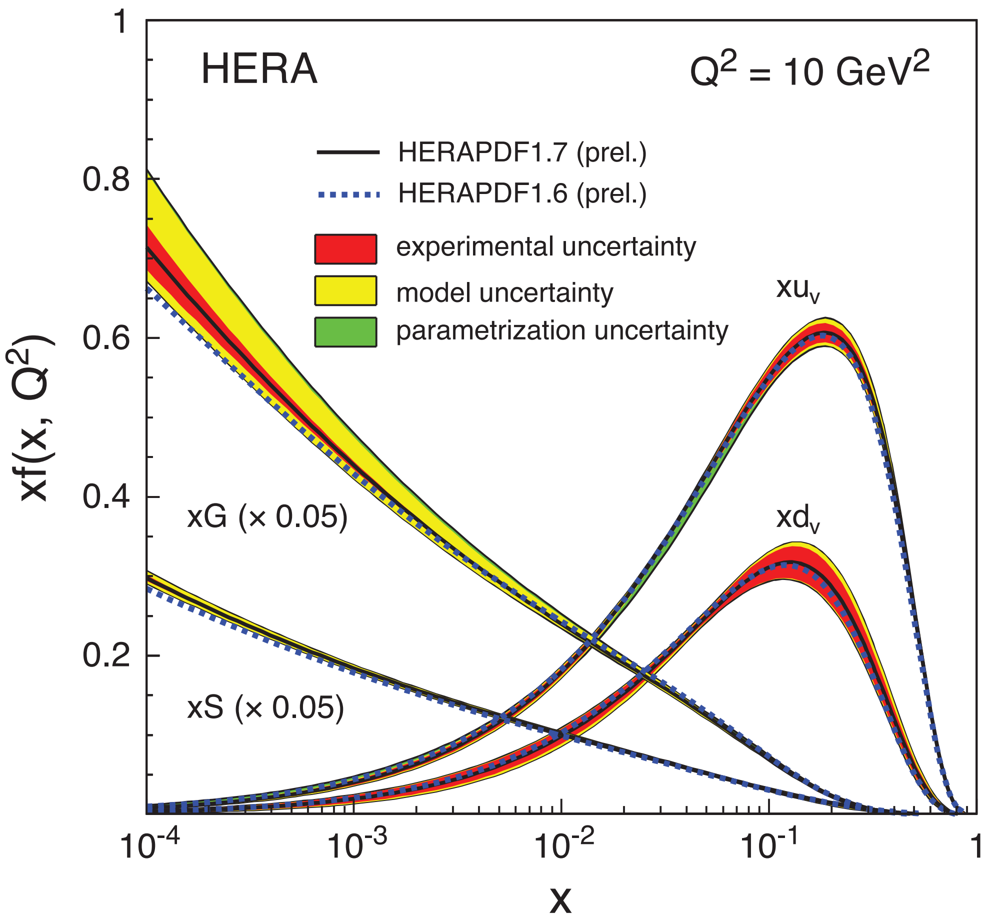
Electroweak

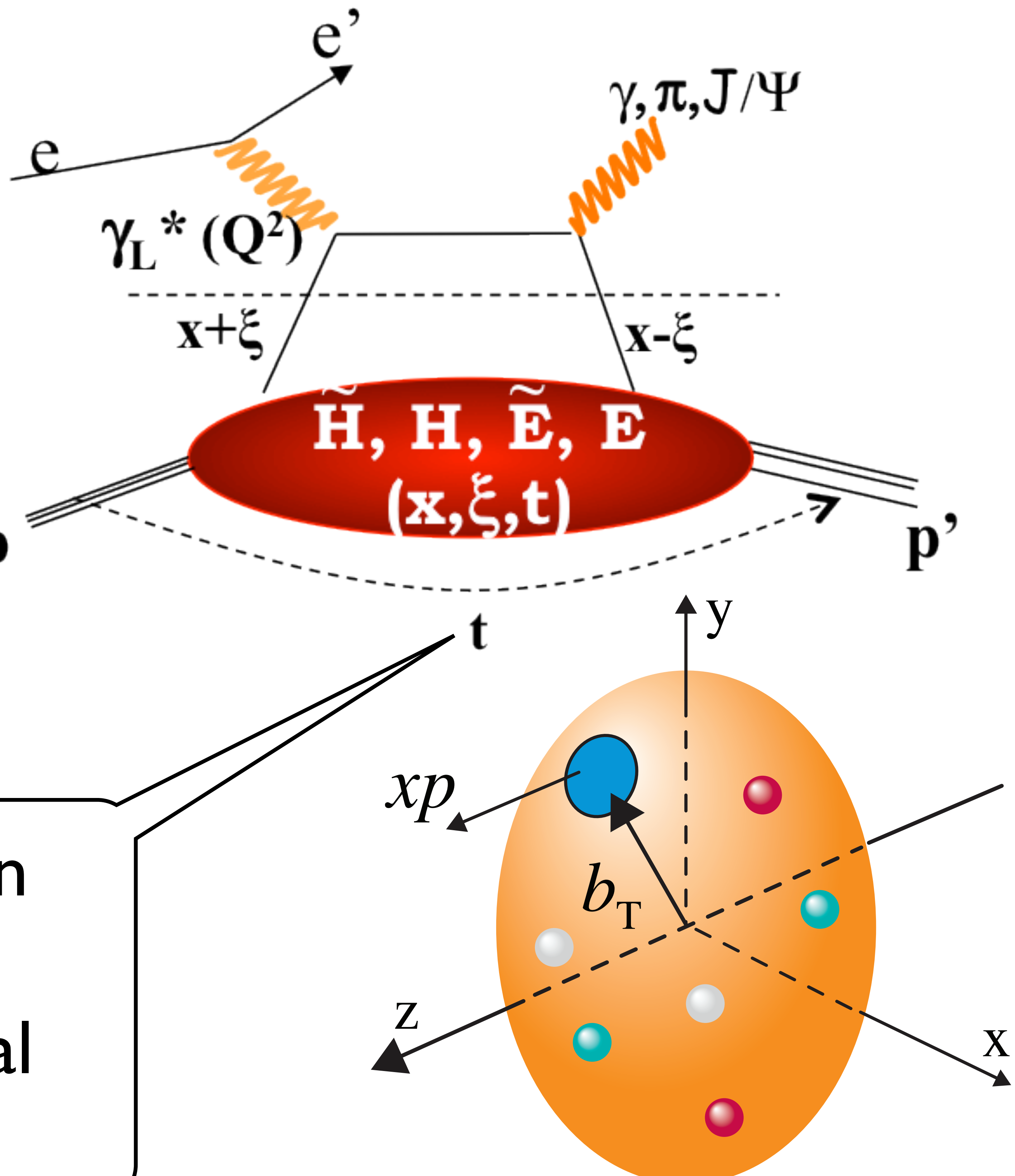
Gluon saturation

Spin

Imaging

PDFs are 1D objects

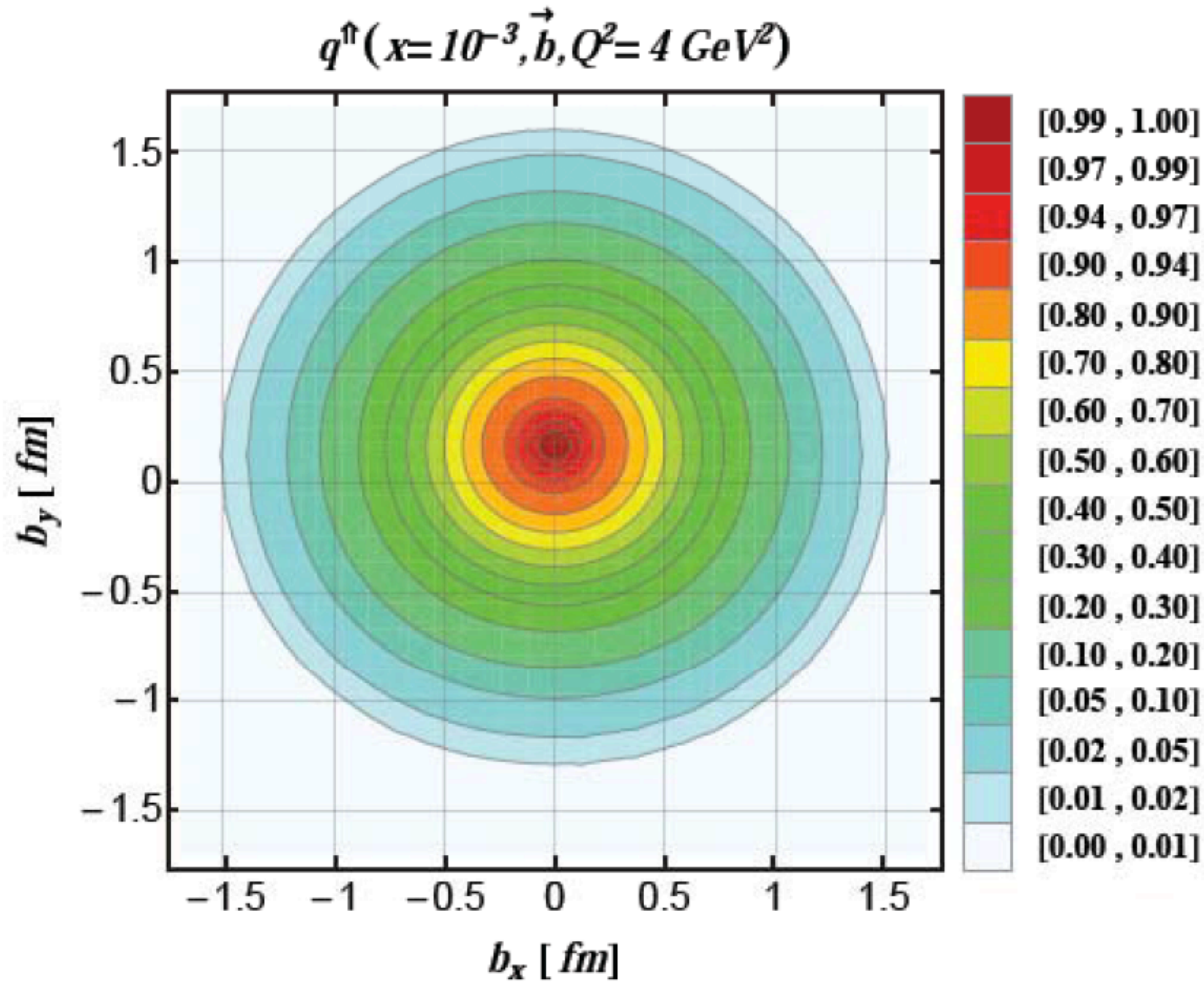




Momentum transfer, t, in exclusive reactions → Access transverse spatial distribution

Imaging

- Nucleon "tomography": extend our view of the nucleon beyond the 1D image we have today



Imaging

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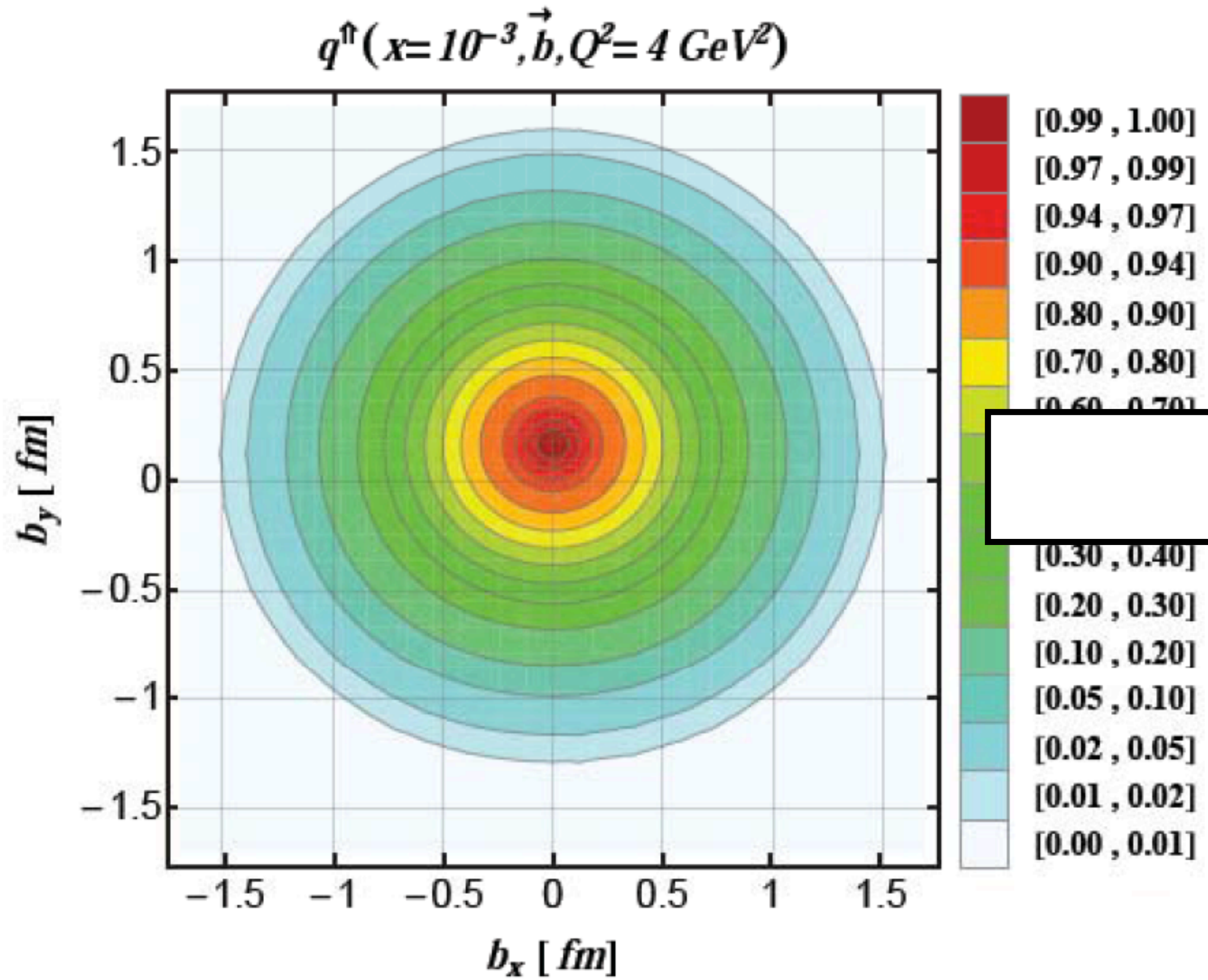
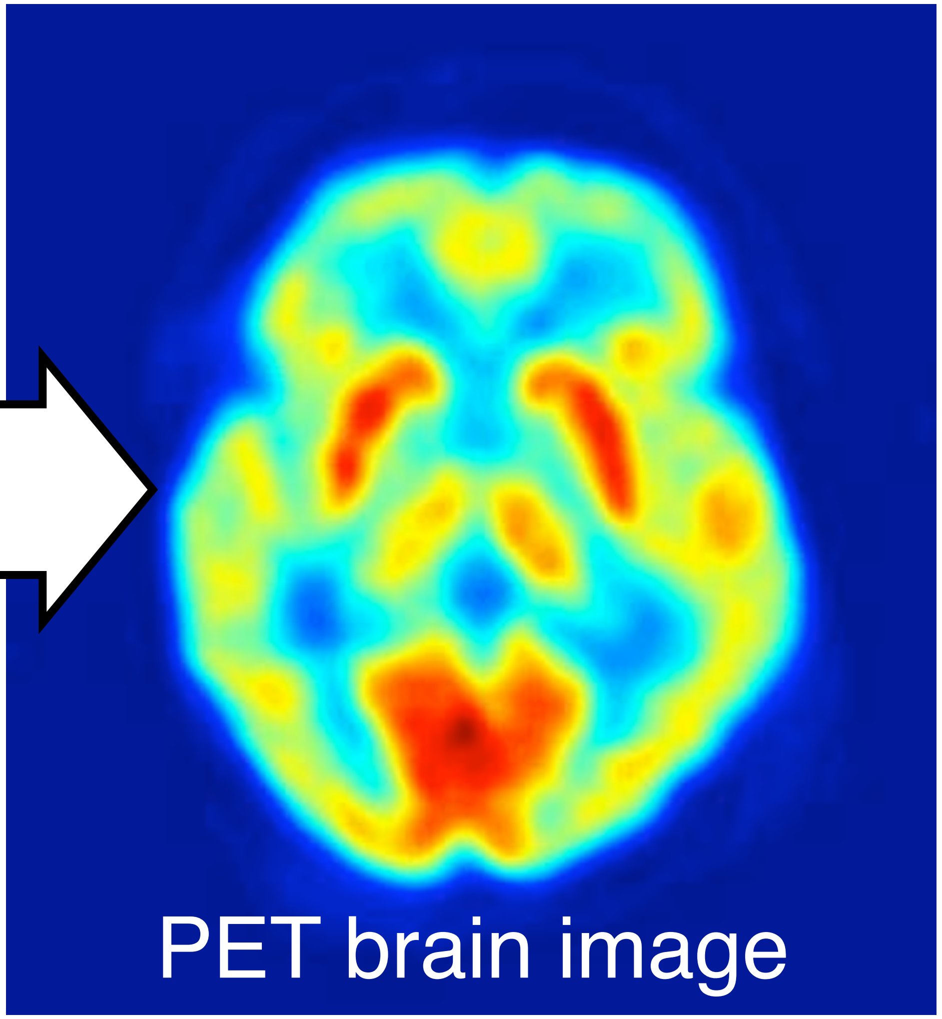
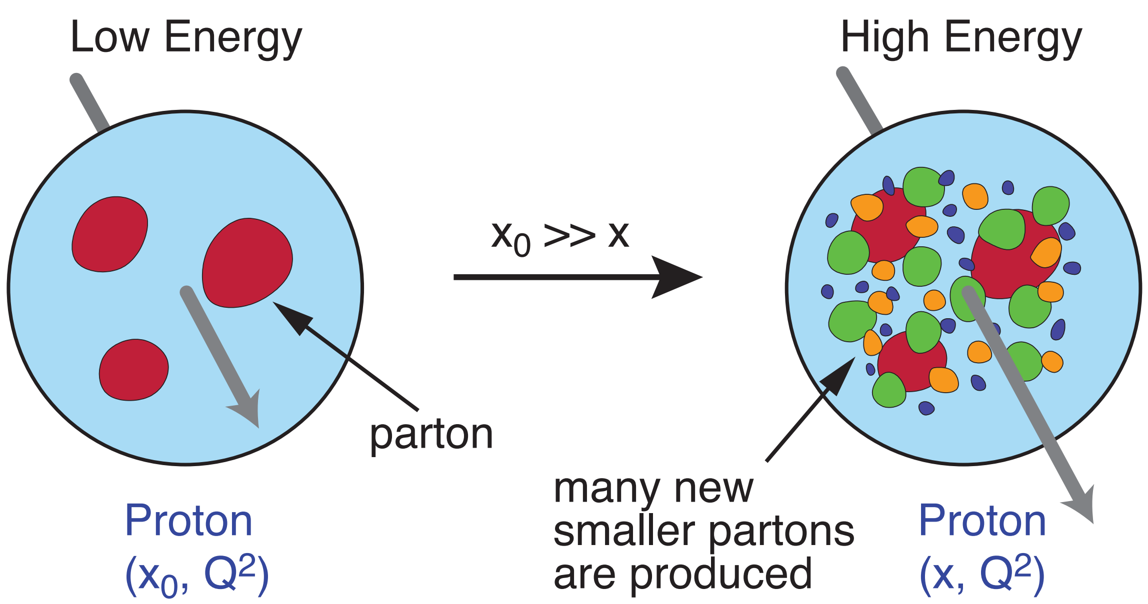


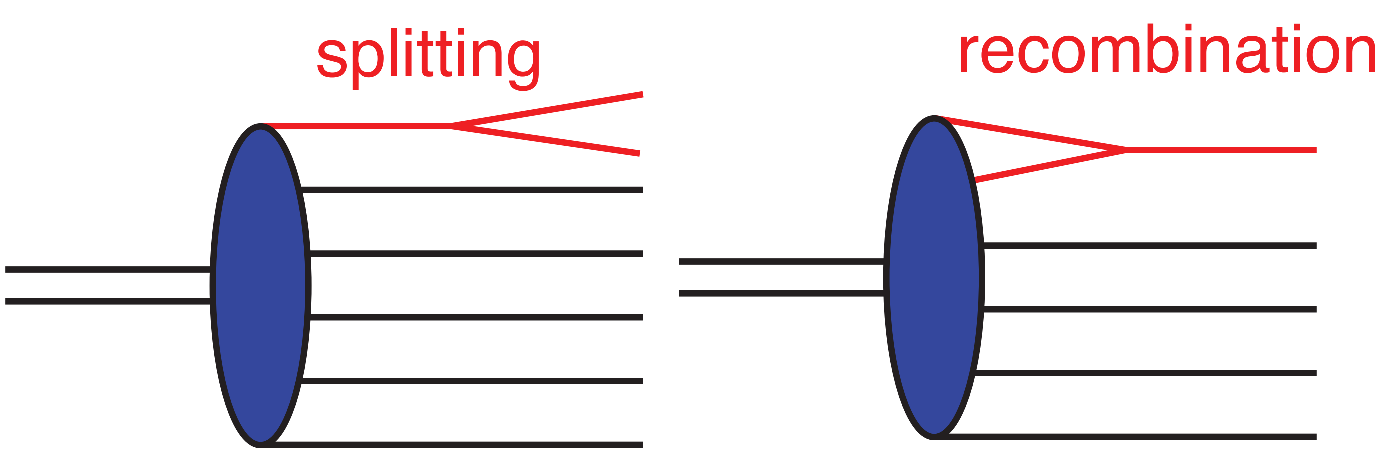


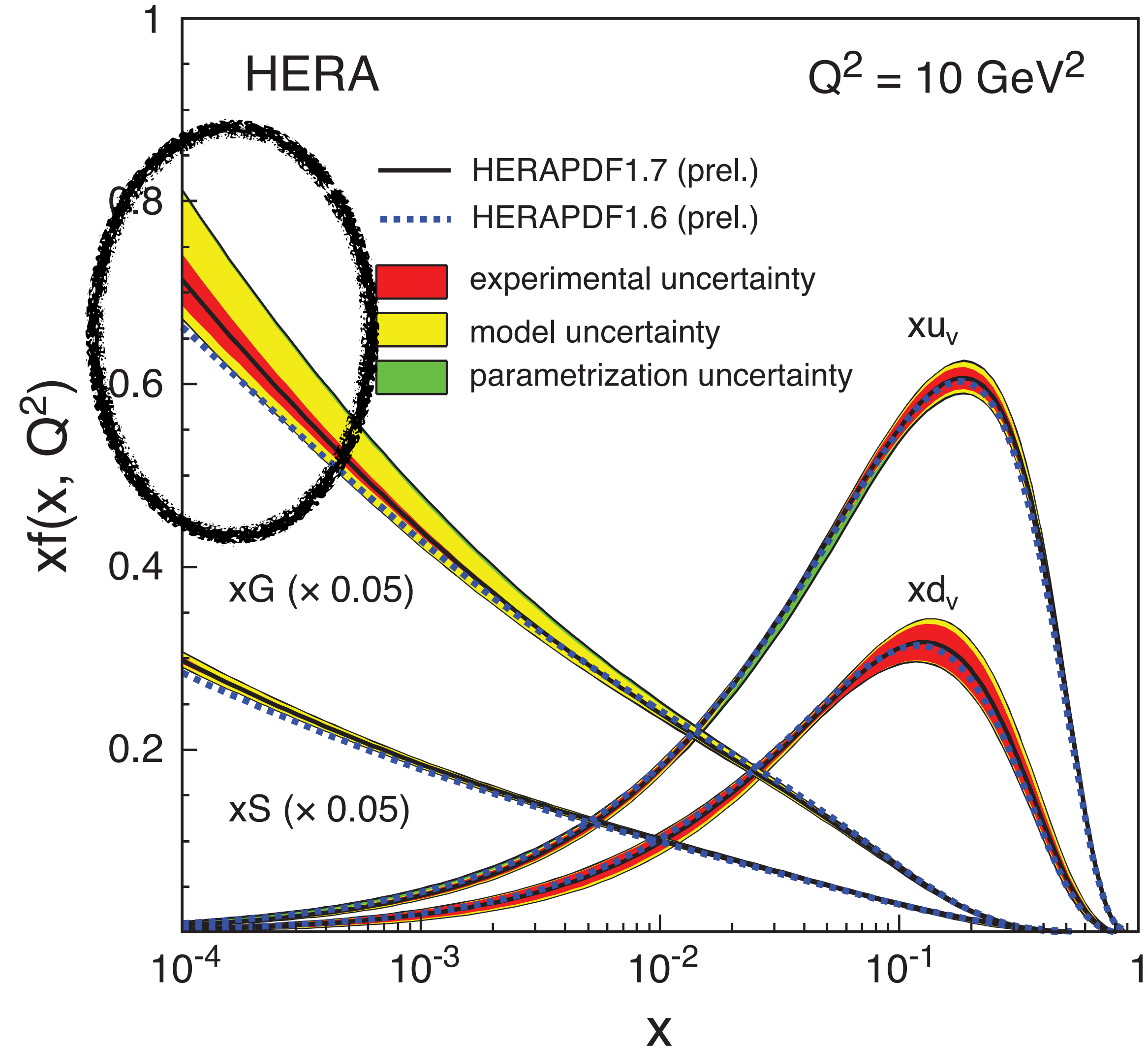
Gluon saturation

- Understand nuclear properties at a state of highest gluon density



"Color Glass Condensate"

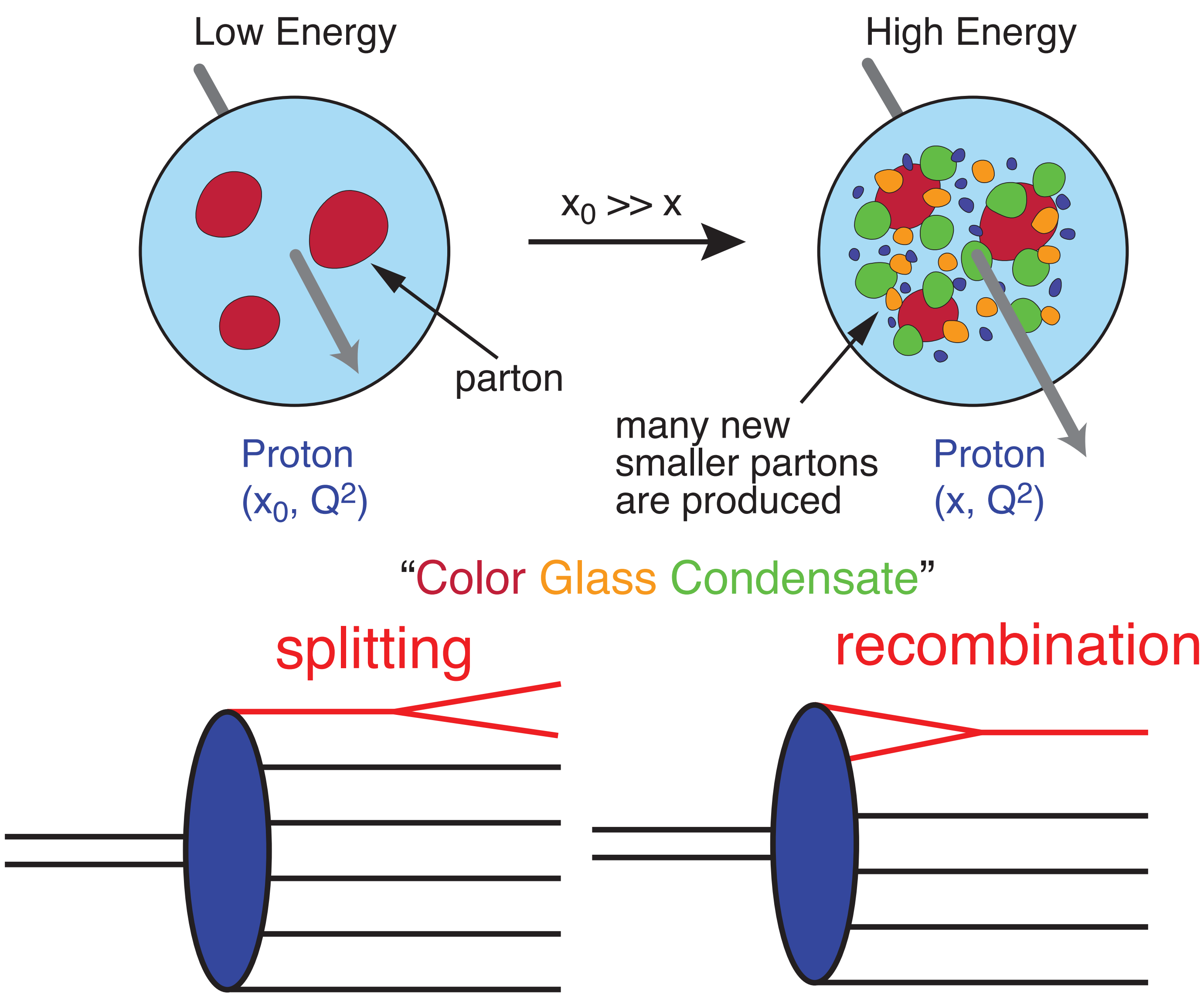


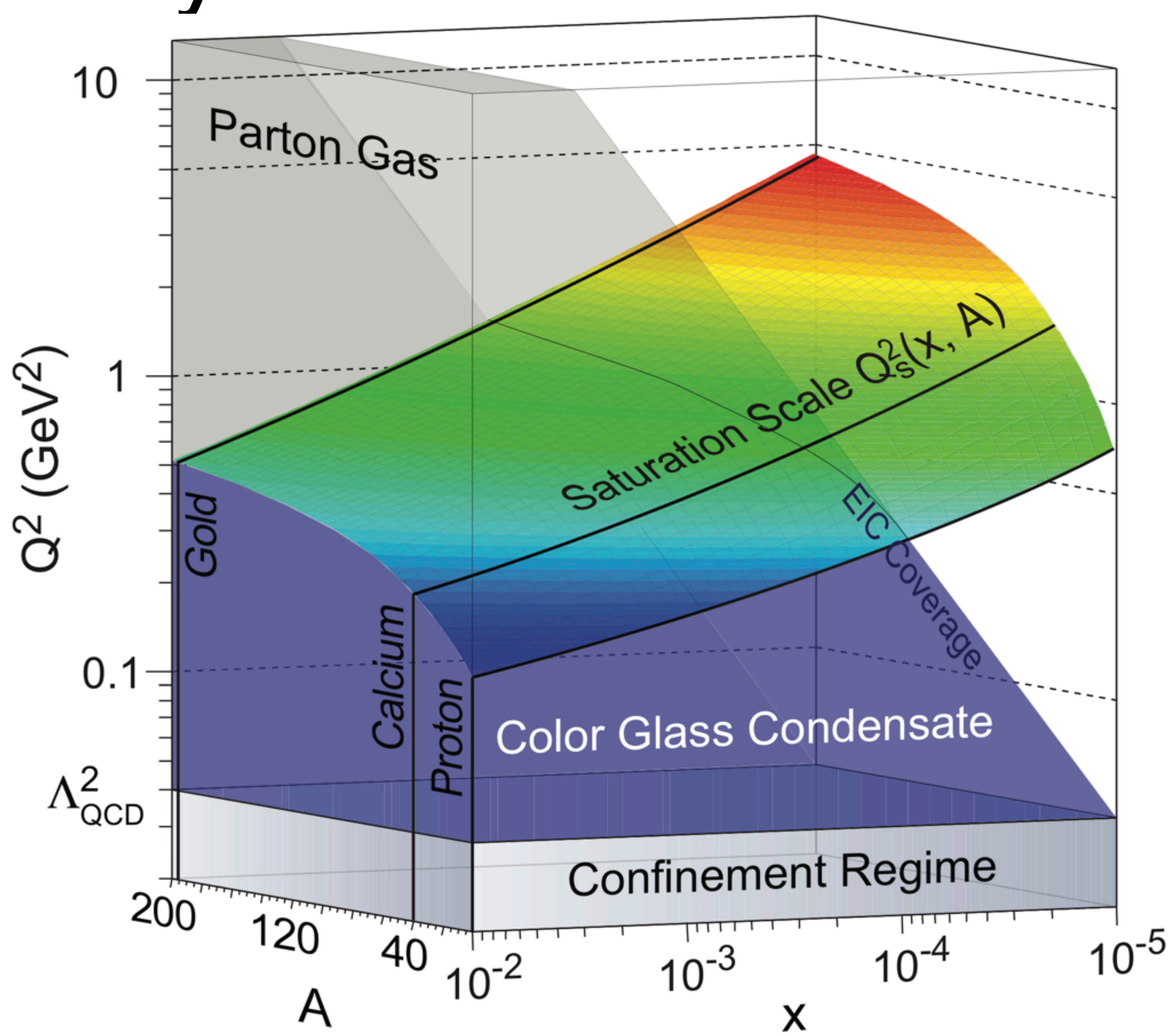


Represents a new regime of QCD physics with "non-linear" evolution

Gluon saturation

- Understand nuclear properties at a state of highest gluon density

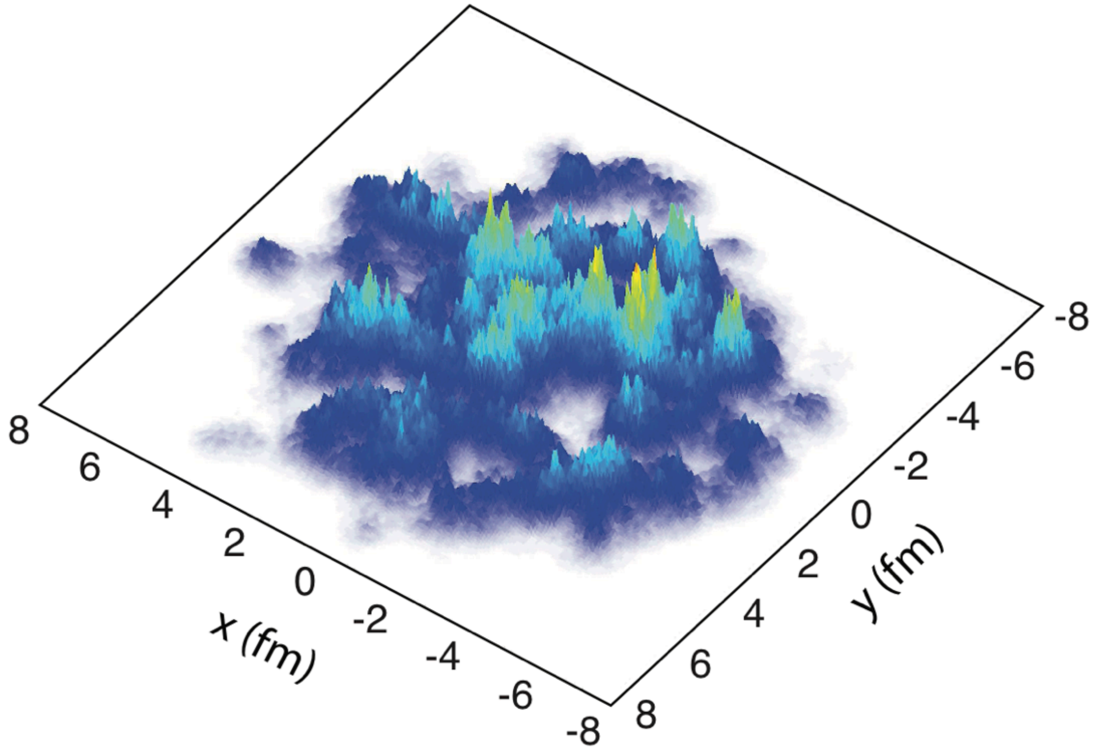


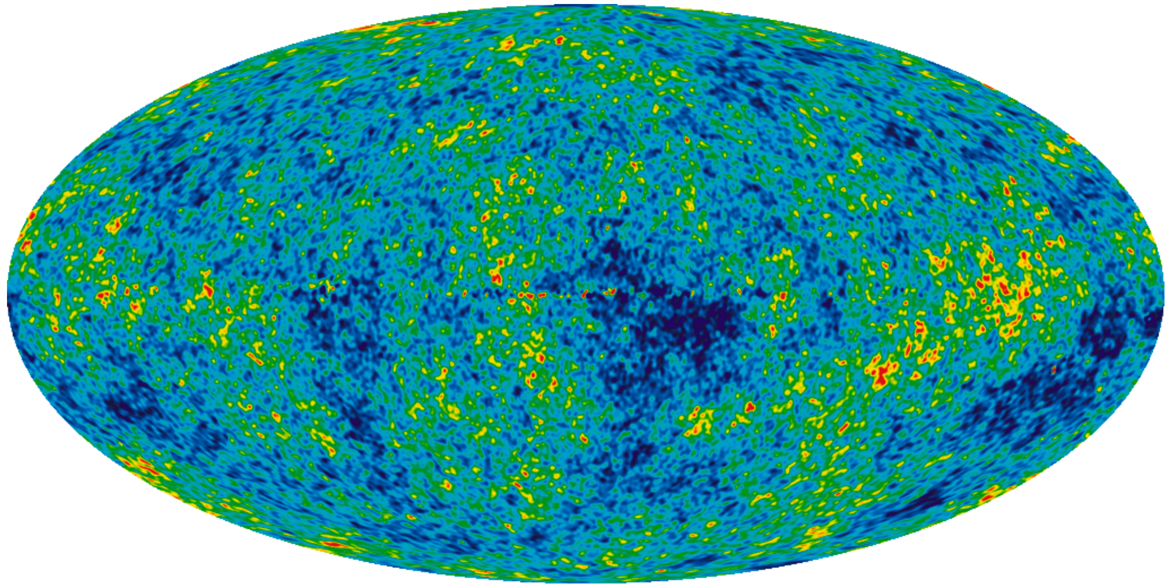


Represents a new regime of QCD physics with "non-linear" evolution

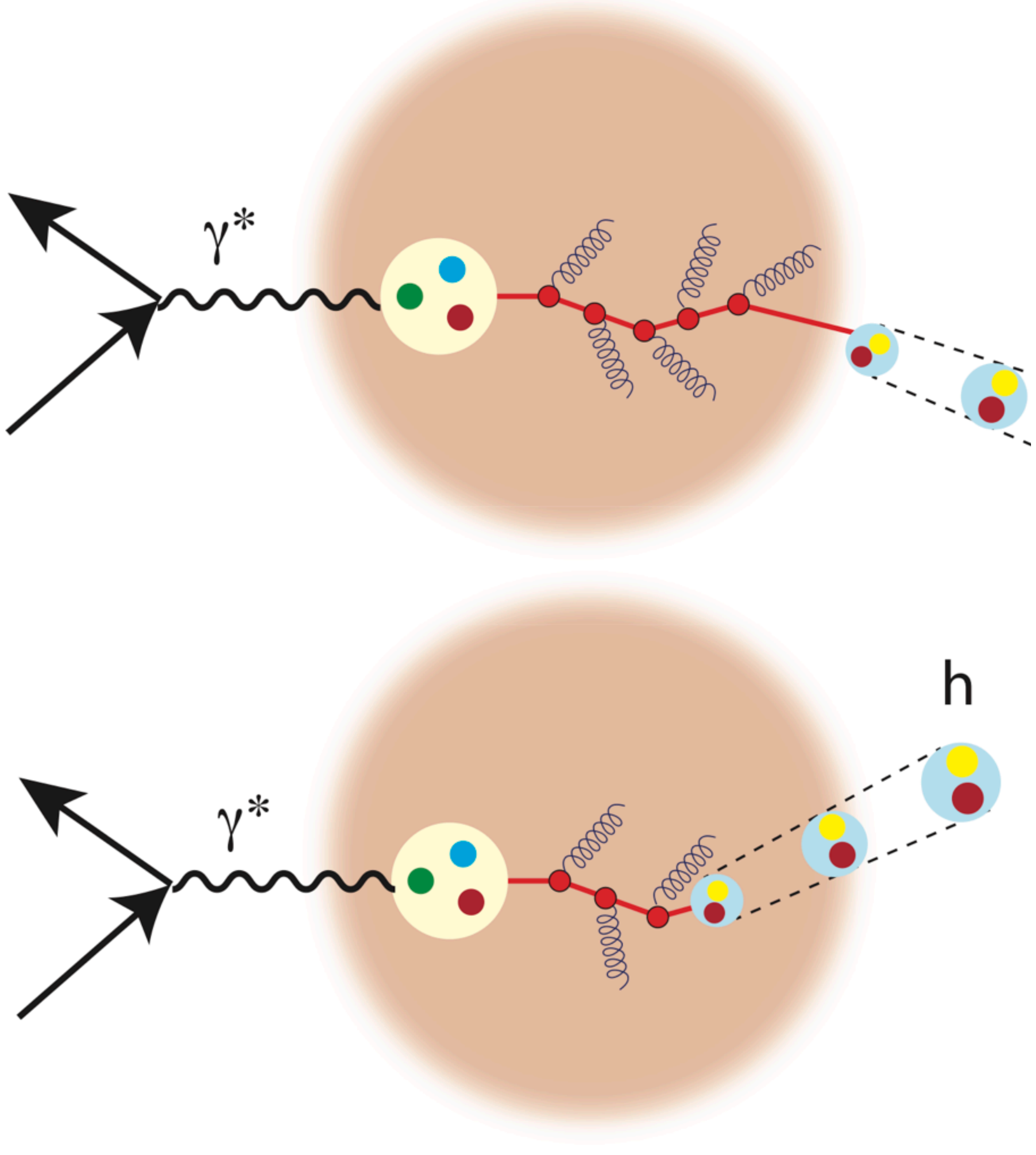
Nuclear environment

What is the nature of the nuclear initial state?



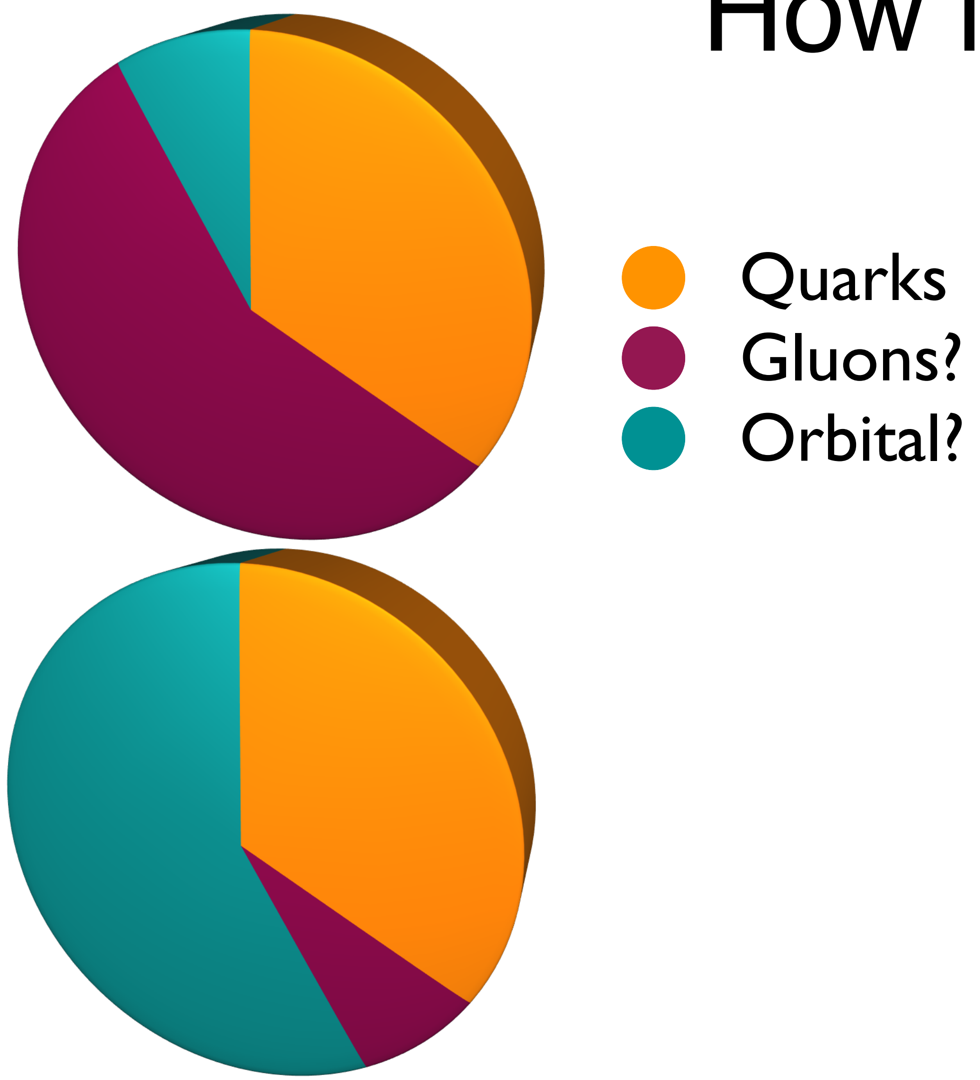


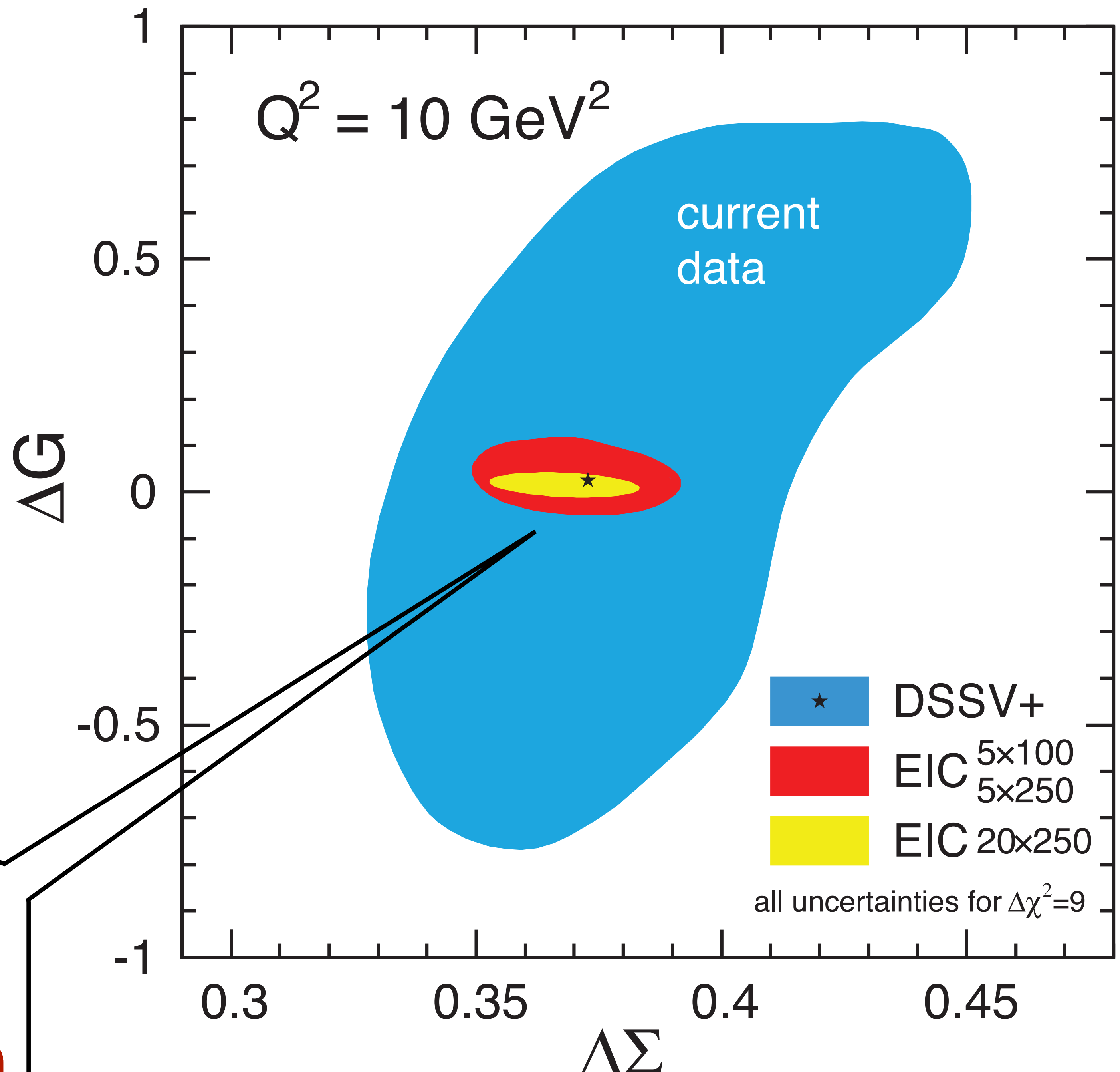
How do partons interact with nuclear matter as they propagate through it?



Spin

How is nucleon spin composed?

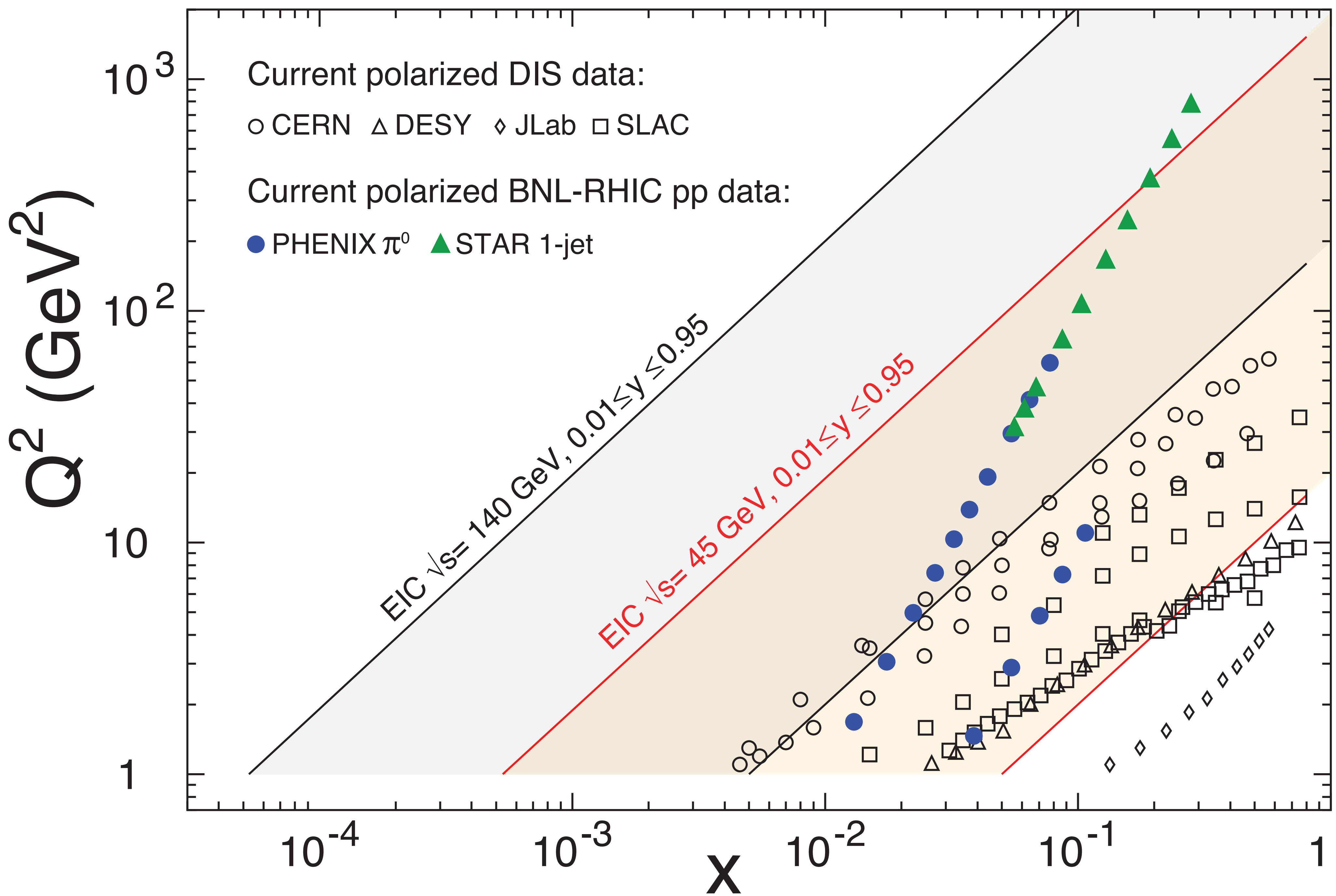




EIC will answer the question of **gluon spin**

Kinematics

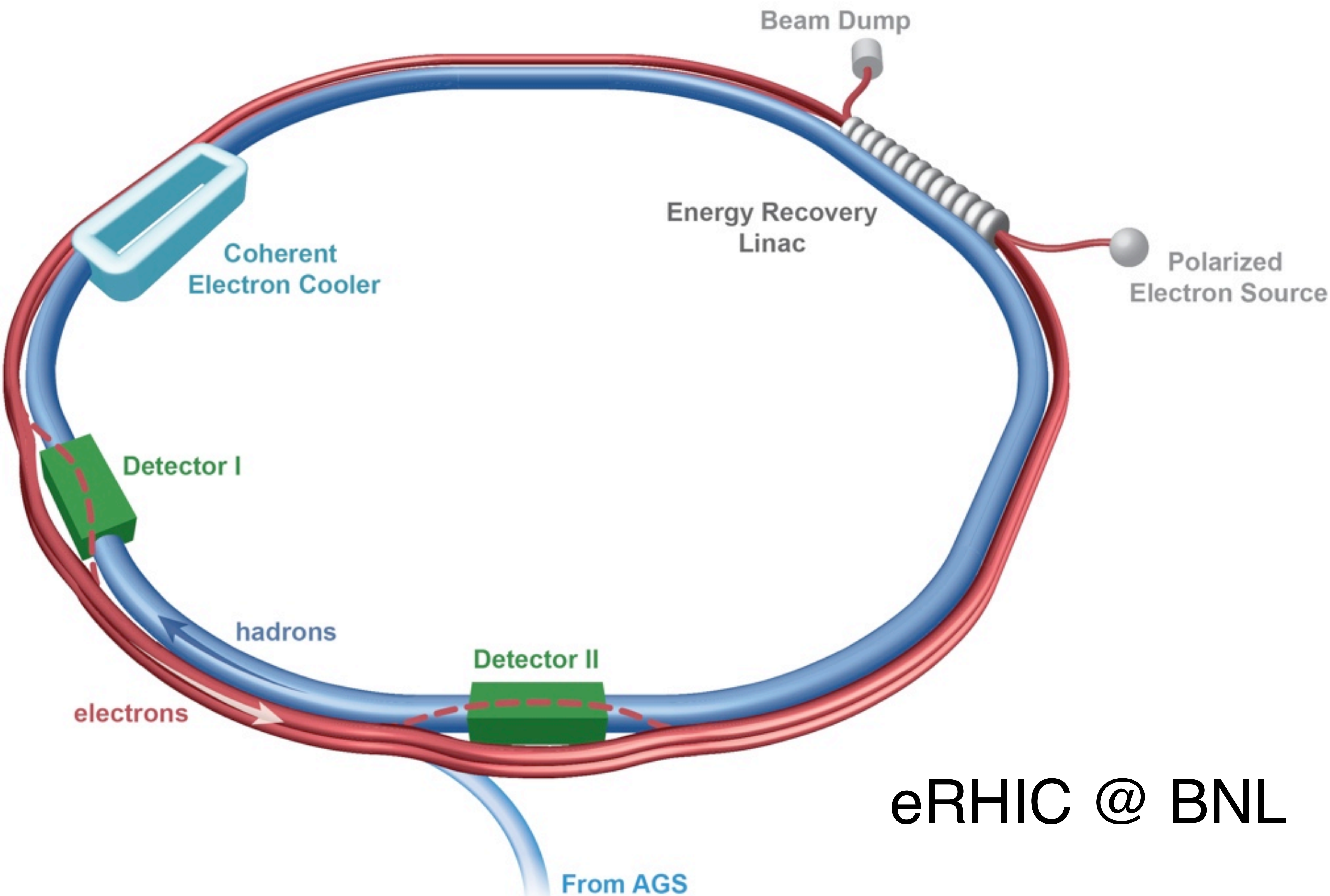
Vastly expands kinematics for polarised DIS



Requirements for an EIC?

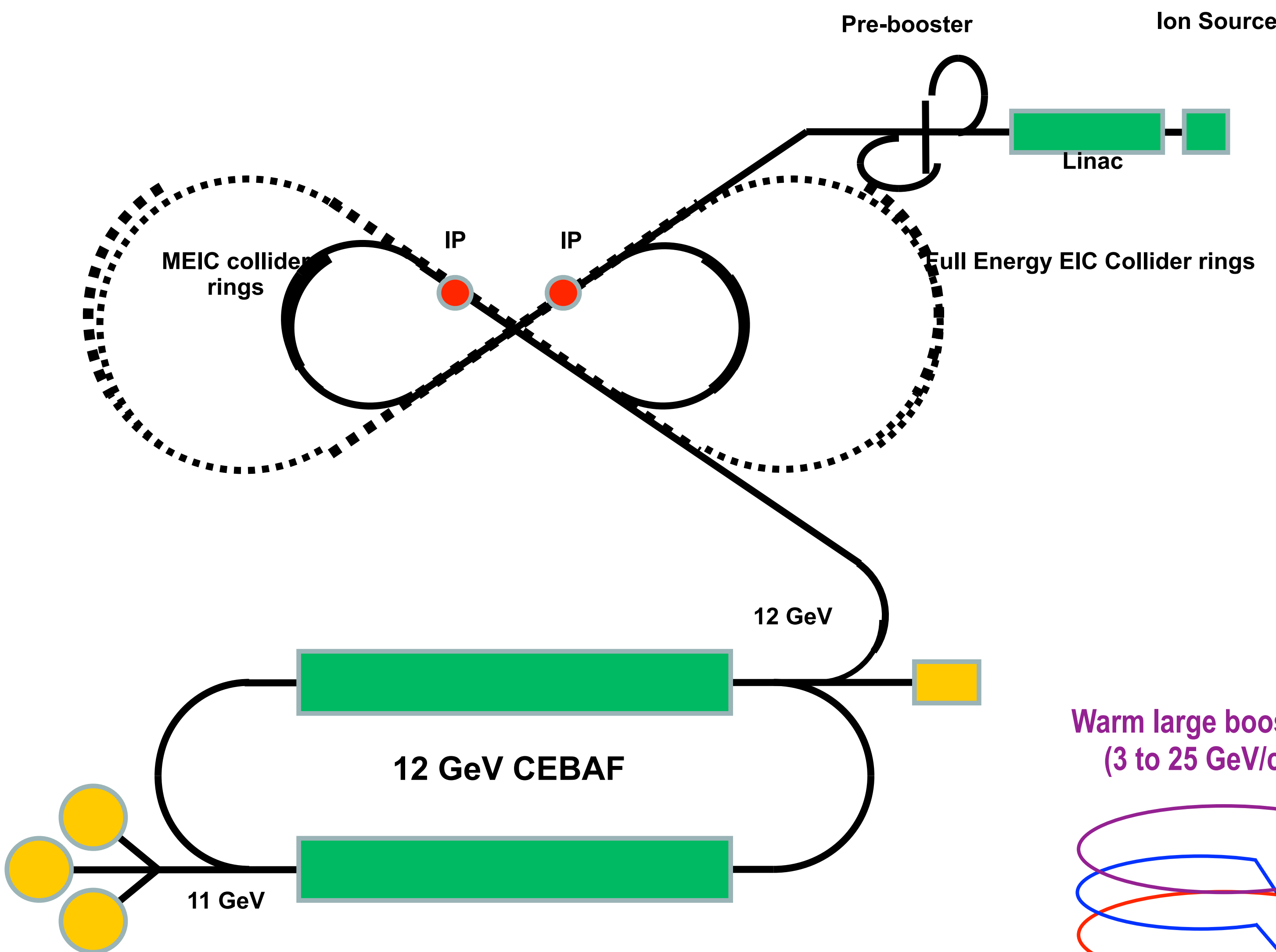
- L up to ~10^{34} cm^{2} s^{-1}: 100-1000x HERA
- Energy - highly variable: $\sqrt{s}$ ~ 30-150 GeV
- **Polarised e**, **p** and **He^3**
- Species: p, light and heavy nuclei
- Detector: acceptance, PID, elastic/ breakup fragments

What might an EIC look like?

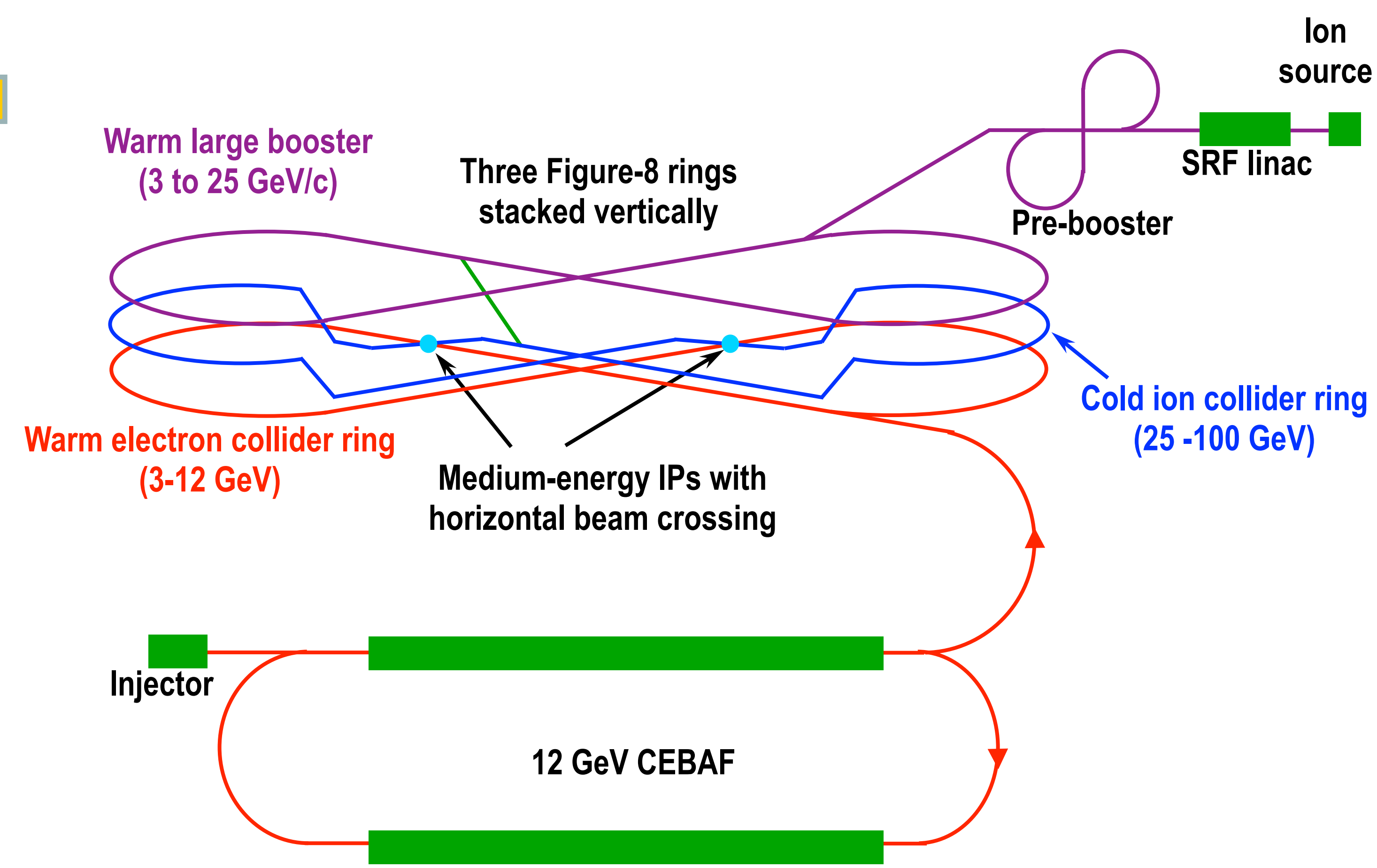


eRHIC @ BNL

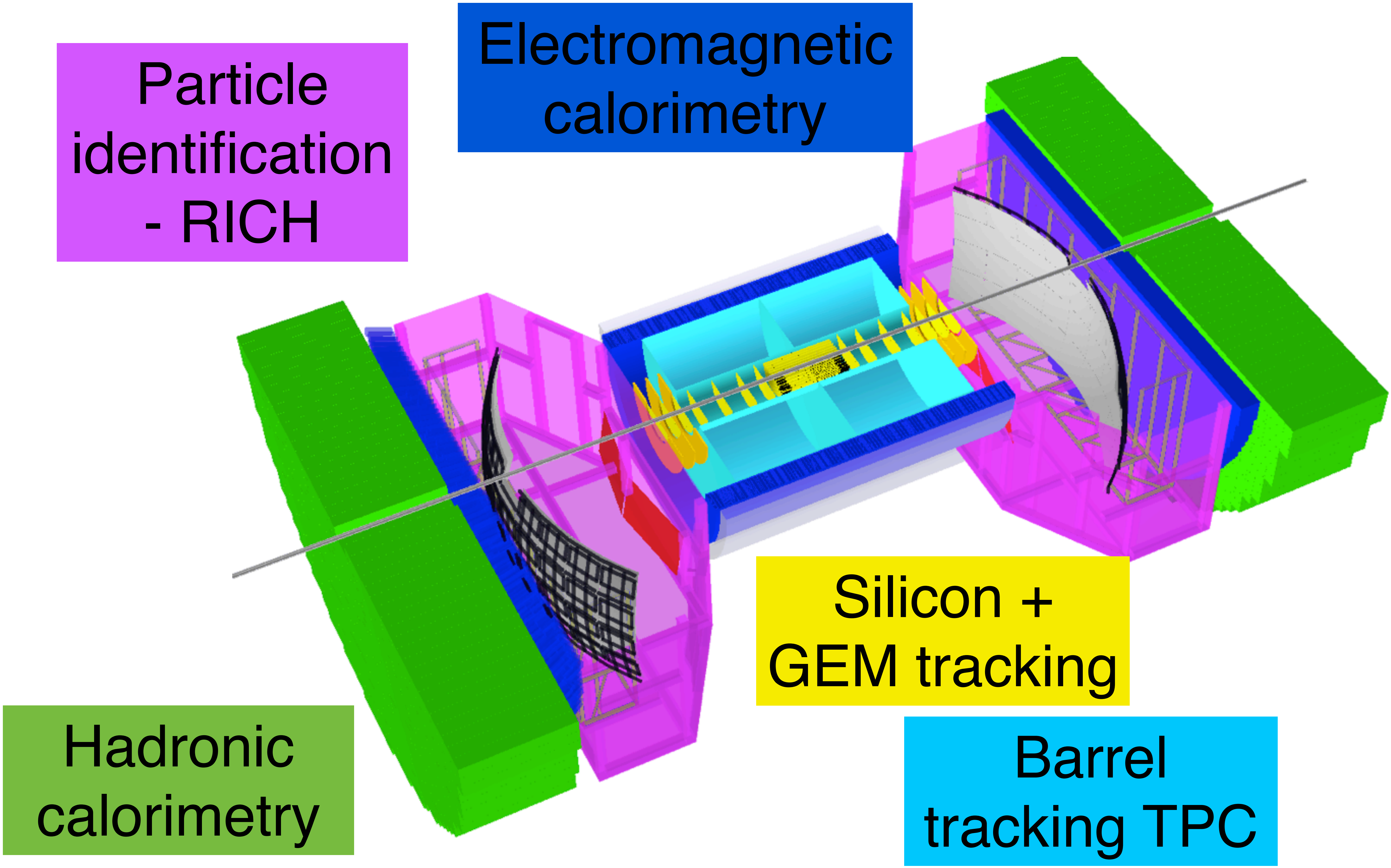
What might an EIC look like?



MEIC @ JLab



A possible EIC detector



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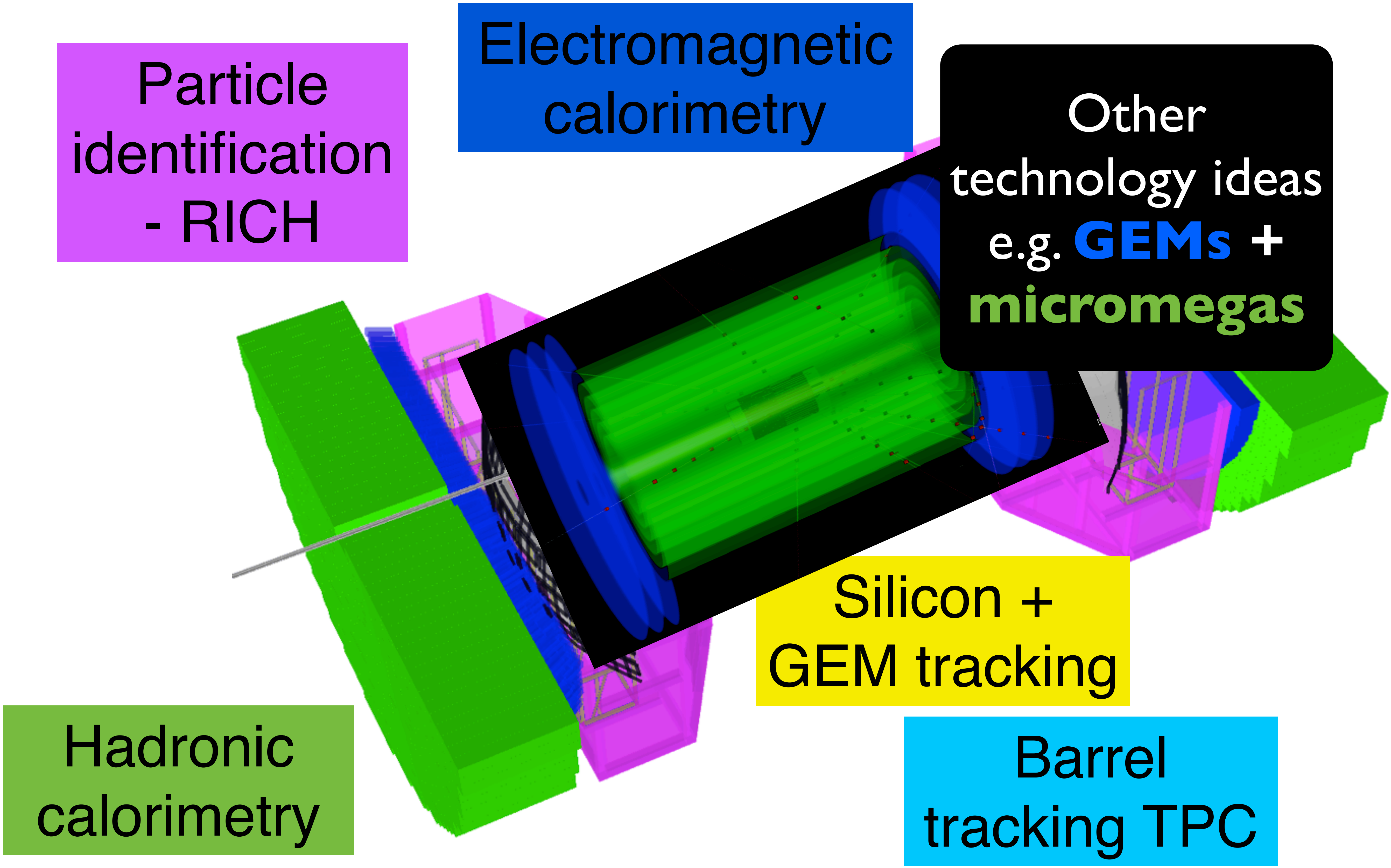
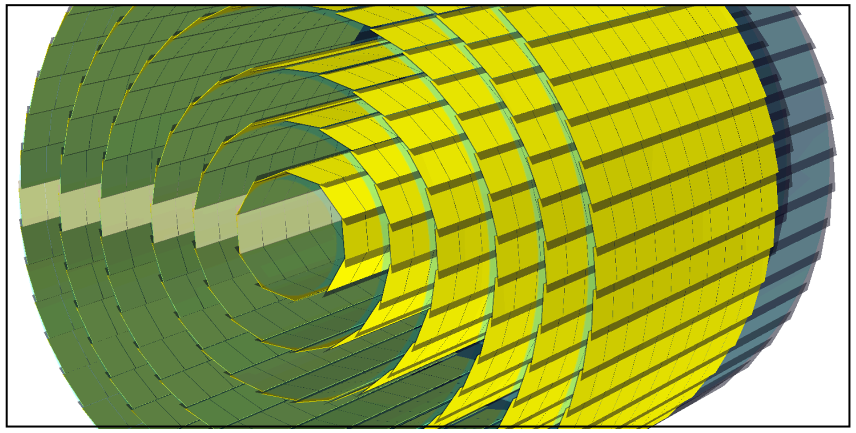
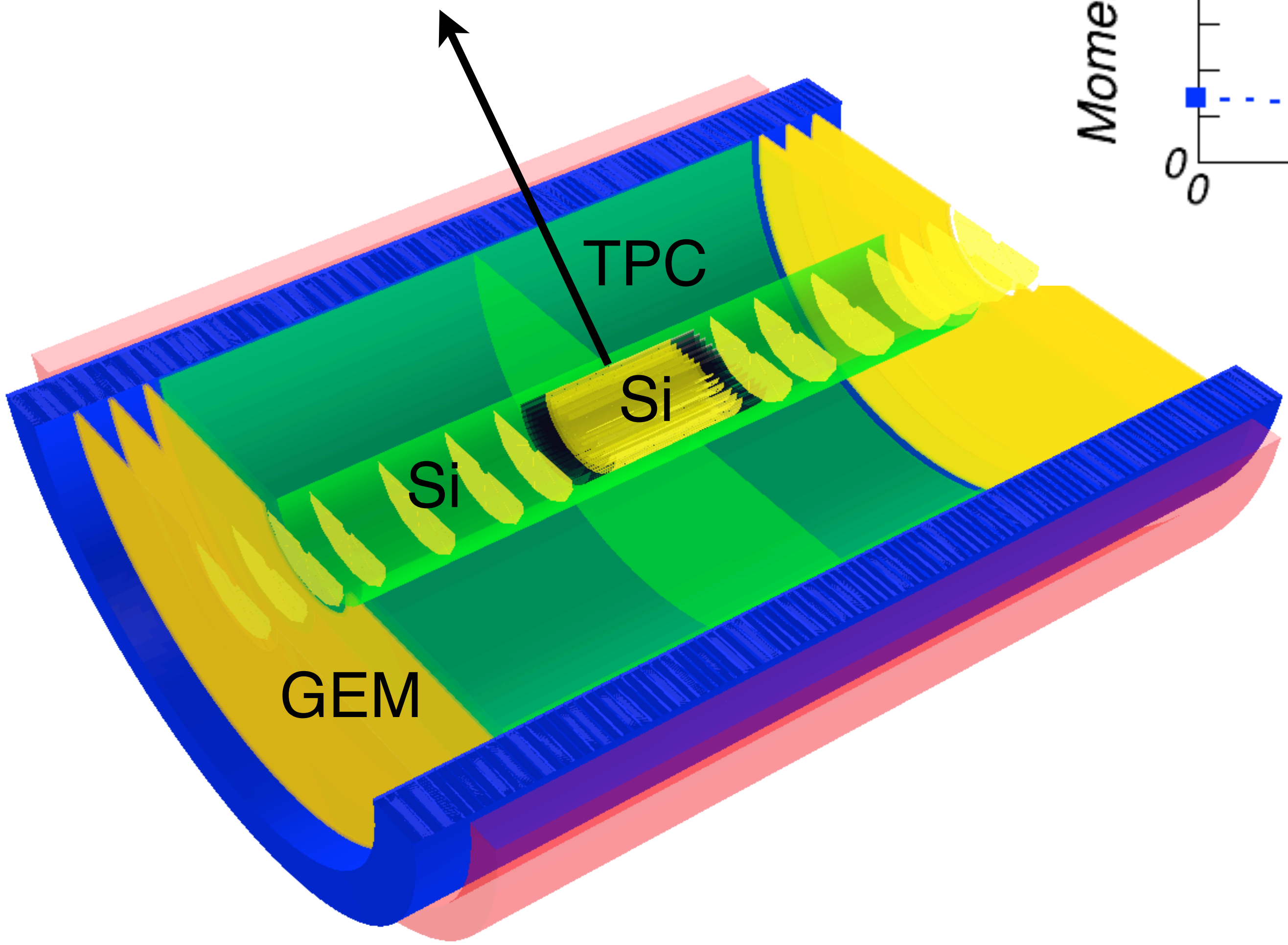
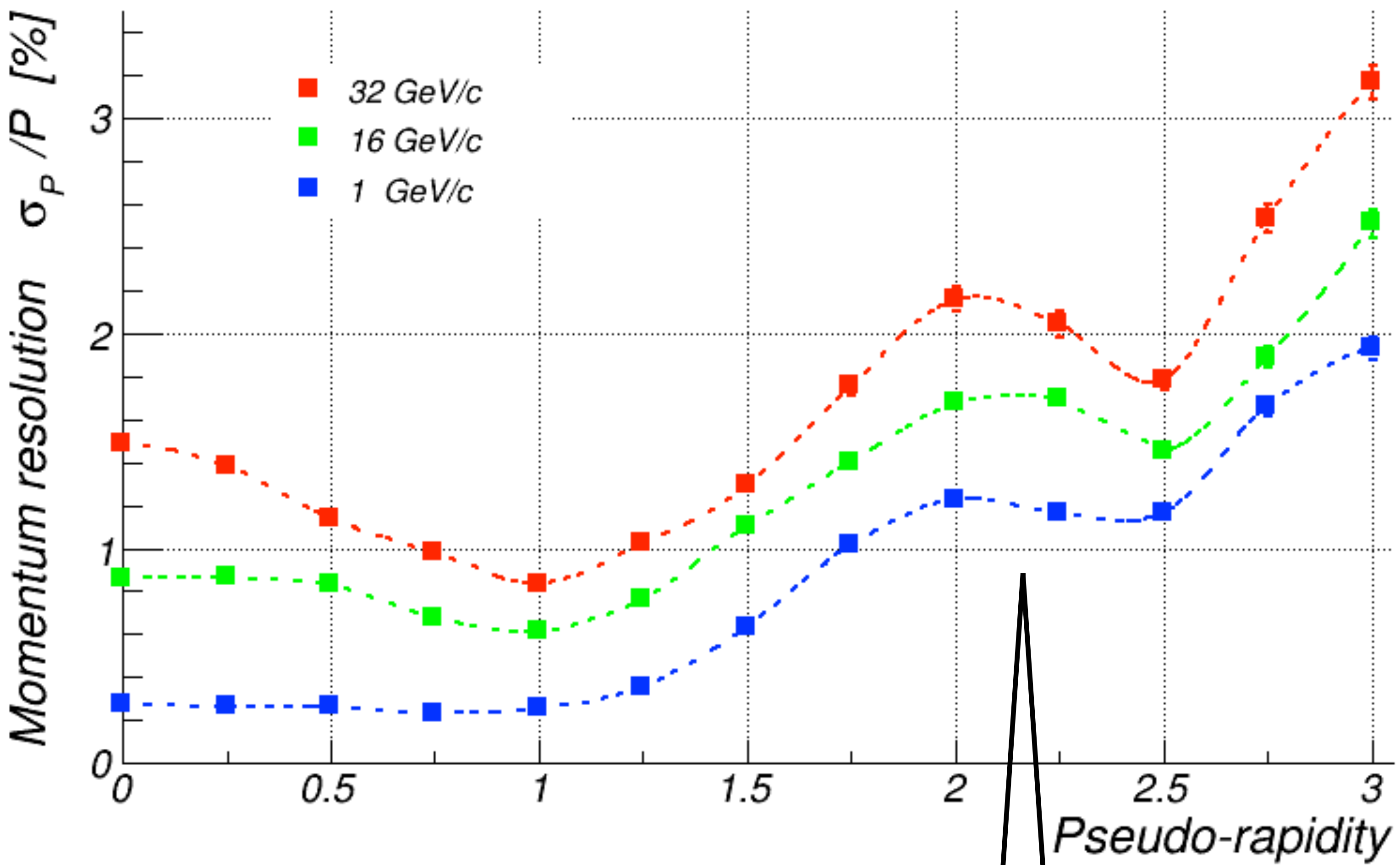


Detector performance

Vertex detector







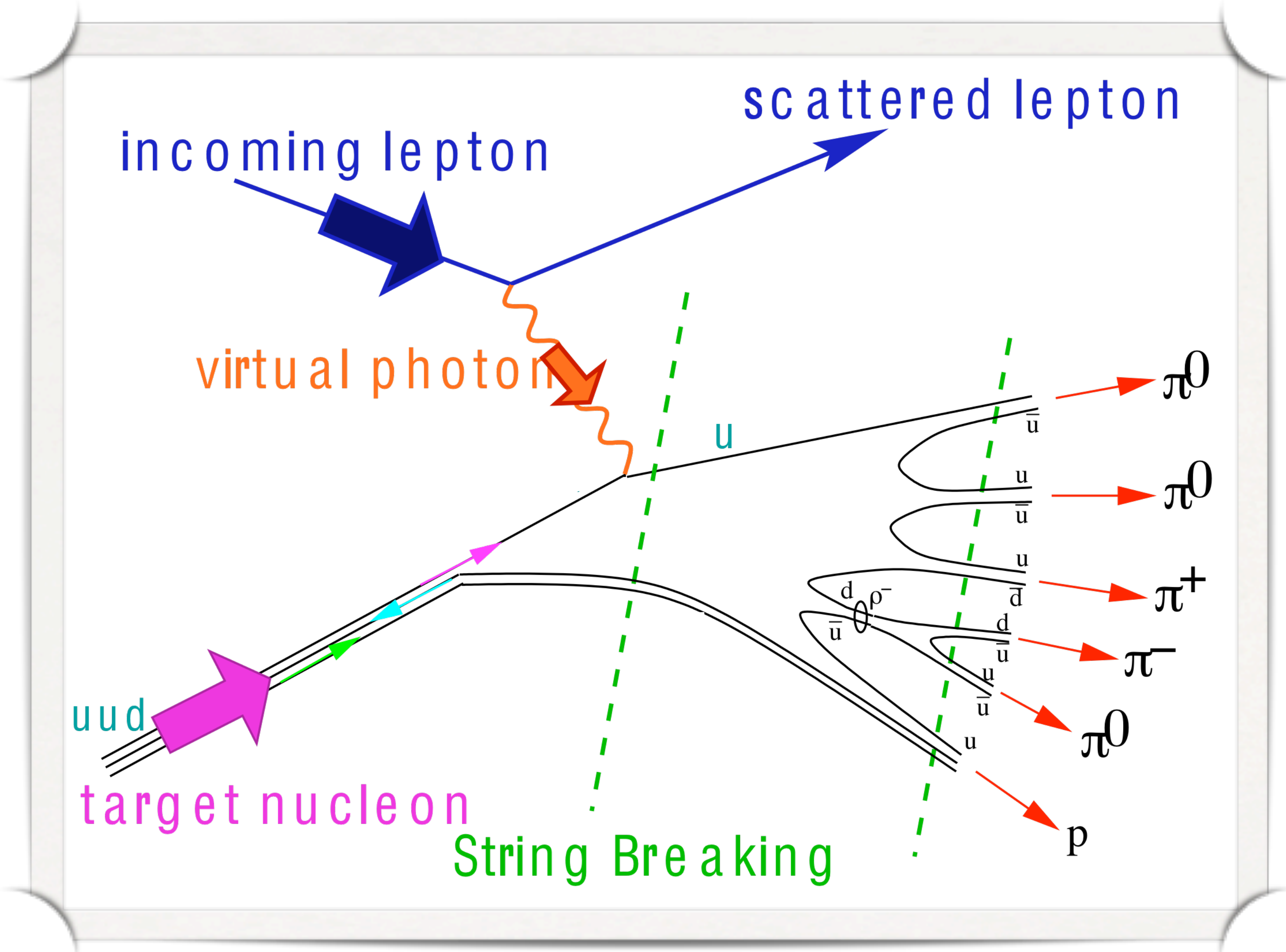
Achieve no worse than ~few% momentum resolution at forward η

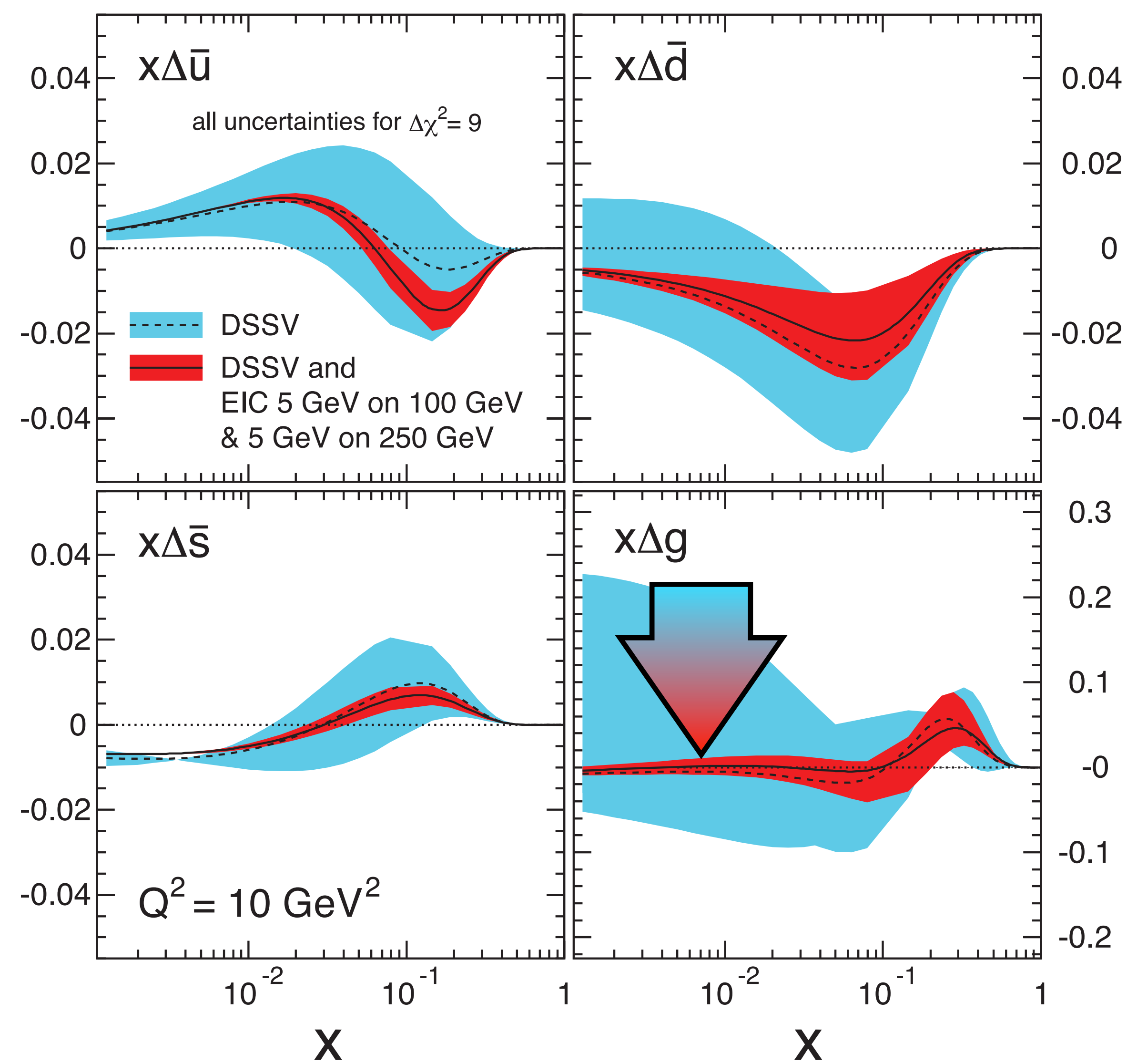
What about electroweak?

Will discuss three topics:

1. Structure functions
2. Weak mixing angle
3. tau-electron conversion?

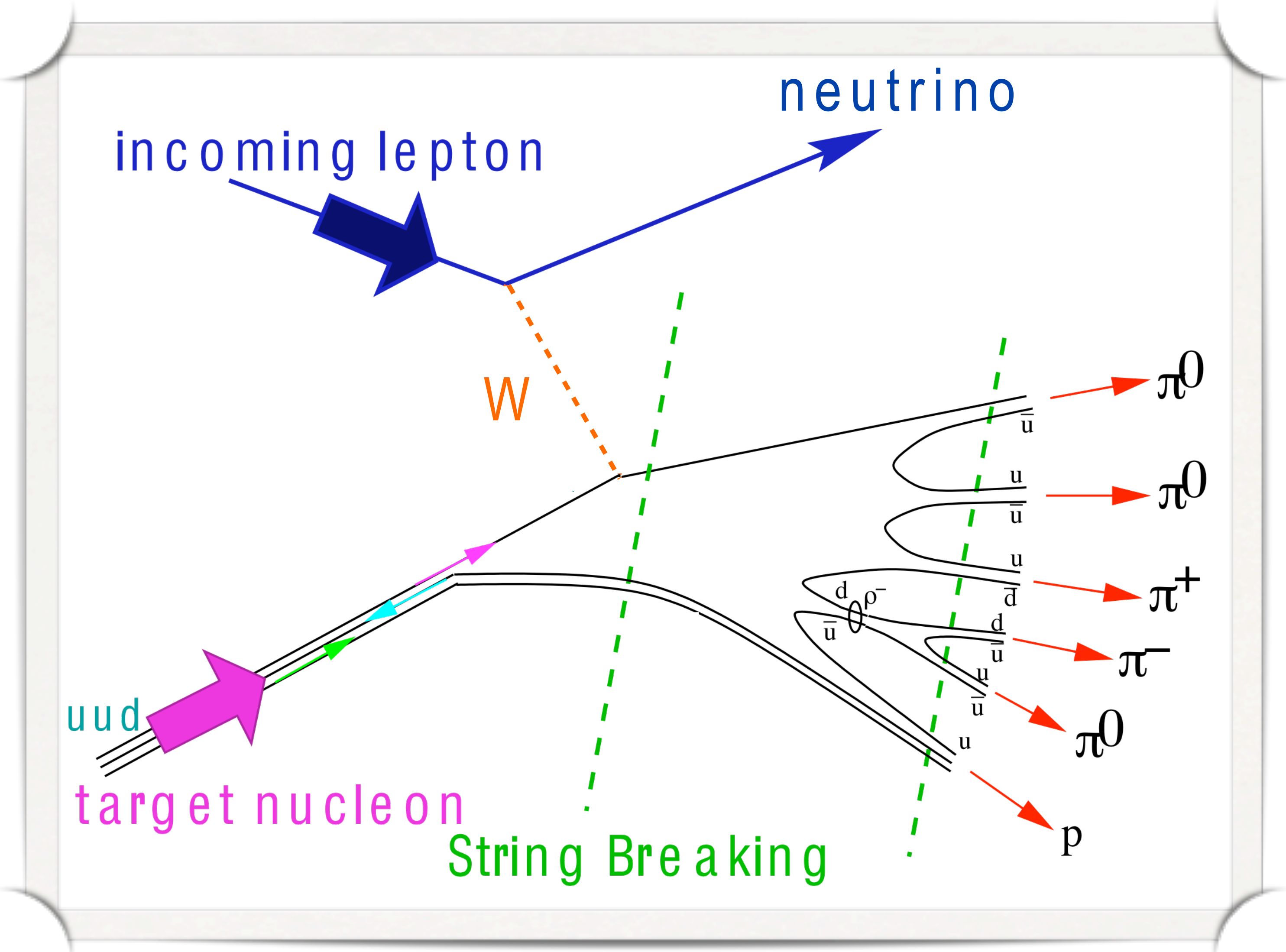
SIDIS vs. charged current DIS





- SIDIS will be a major EIC topic
- http://arxiv.org/pdf/1206.6014v1.pdf

SIDIS vs. charged current DIS



- CC allows **flavour separation** without **fragmentation functions**
- Accesses higher Q^2
- Provides different **flavour combinations**

$$\frac{d^2\Delta\sigma^{W^-,N}}{dxdy} = \frac{2\pi\alpha_{\rm em}^2}{xyQ^2}\eta[2Y_- x g_1^{W^-,N} - Y_+ g_4^{W^-,N} + y^2 g_L^{W^-,N}] \qquad g_L \equiv g_4 - 2xg_5$$

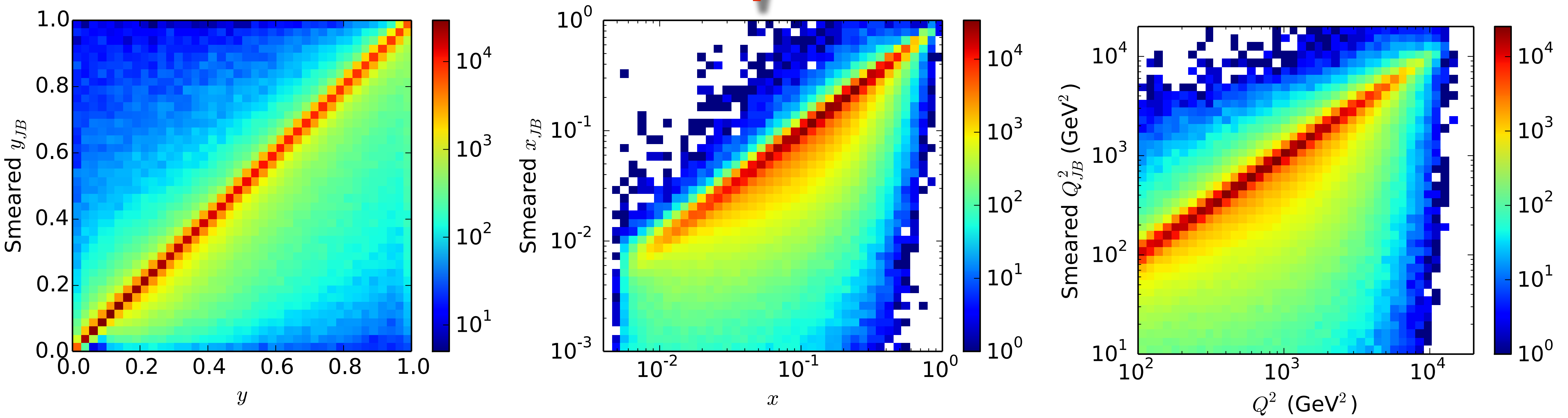
$$g_1^{W^-,p}(x) = \Delta u(x) + \Delta\bar{d}(x) + \Delta c(x) + \Delta\bar{s}(x), \quad g_5^{W^-,p}(x) = -\Delta u(x) + \Delta\bar{d}(x) - \Delta c(x) + \Delta\bar{s}(x)$$

Aside: kinematic reconstruction

In a CC event there is **no scattered electron!**

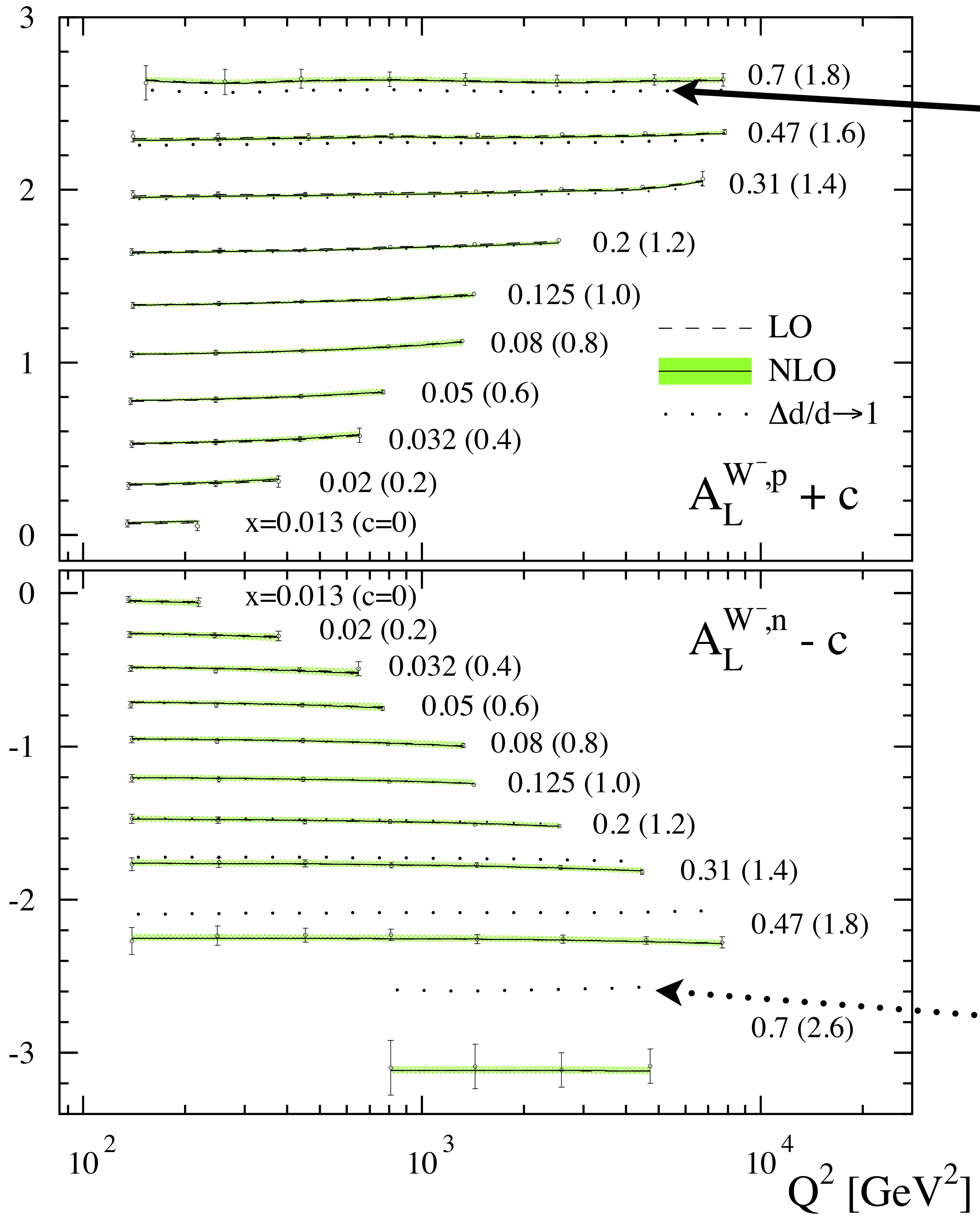
Reconstruct kinematics from **hadronic final state**

$$y_{\mathrm{JB}} = \frac{\sum_i (E_i - p_{z,i})}{2E_e} \qquad x_{\mathrm{JB}} = \frac{Q^2_{\mathrm{JB}}}{y_{\mathrm{JB}} S} \qquad Q^2_{\mathrm{JB}} = \frac{p^2_{T,h}}{1 - y_{\mathrm{JB}}},$$



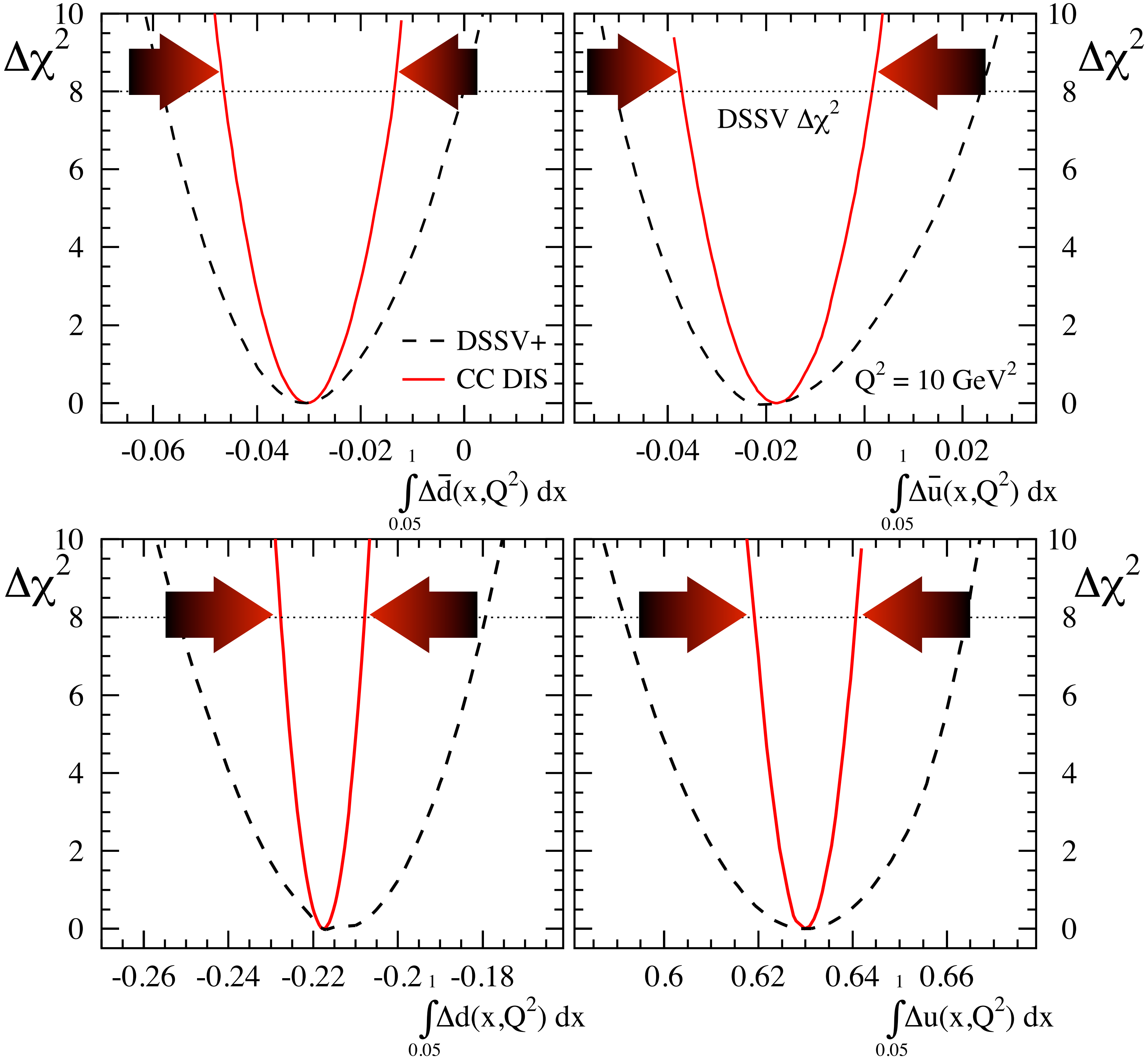
A_L^W

$$A_L^{W^-,N} \equiv \frac{d^2\Delta\sigma^{W^-,N}/dxdy}{d^2\sigma^{W^-,N}/dxdy}$$



- Large A_L^W at large x ~80%
- NLO effects small
- $\sigma(A_L^W)/A_L^W$ small
  - <~5% for **p**
  - <~8% for **n**
  - ~25% at x limits
- Sensitive to "helicity retention"

Impact on global analyses

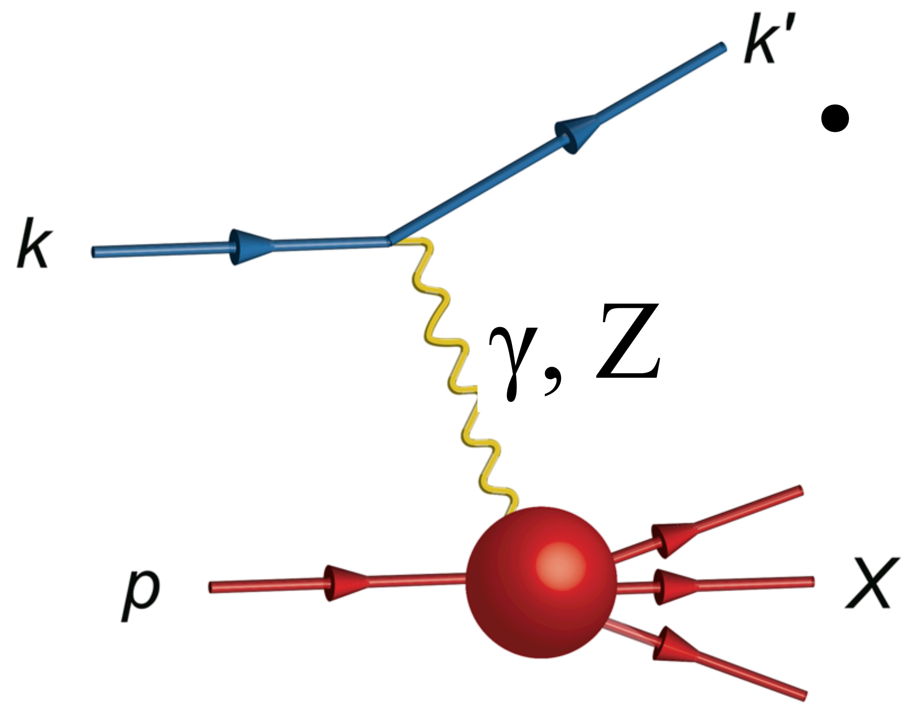


- Constrain **u**, **d** & **anti-q** helicities
- Flavour constraint independent of **fragmentation**
- Important check on **SIDIS**
  - low Q^2, higher twist effects

PHYSICAL REVIEW D **88**, 114025 (2013)

Prospects for charged current deep-inelastic scattering off polarized nucleons at a future electron-ion collider

Weak mixing angle



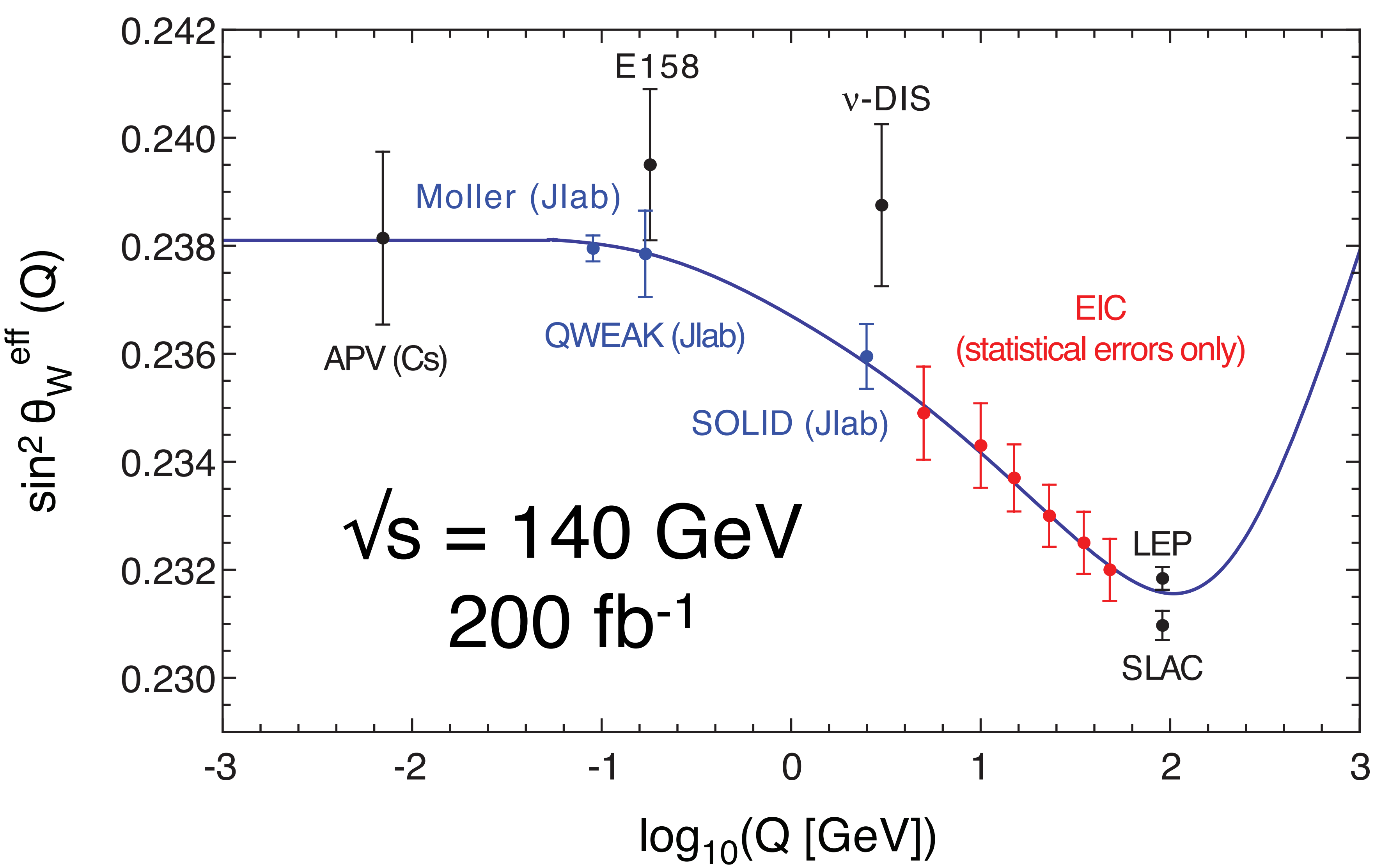
- Measure A_{PV} in e-^{2}H
  - average over hadron polarisation
  - difference between right- and left-handed e

$$\mathcal{L}^{PV} = \frac{G_F}{\sqrt{2}}[\bar{e}\gamma^\mu\gamma_5 e(C_{1u}\bar{u}\gamma_\mu u + C_{1d}\bar{d}\gamma_\mu d) + \bar{e}\gamma^\mu e(C_{2u}\bar{u}\gamma_\mu\gamma_5 u + C_{2d}\bar{d}\gamma_\mu\gamma_5 d)]$$

- Relate A_{PV} to $C_{i,j}$ couplings in PV part of e-hadron interaction
  - Extract $(2C_{1u}-C_{1d})$ and $(2C_{2u}-C_{2d})$ couplings as function of Q^2
  - $C_{i,j}$ couplings are function of $\sin^2\theta_W$
- High Q^2 → suppress higher-twist effects

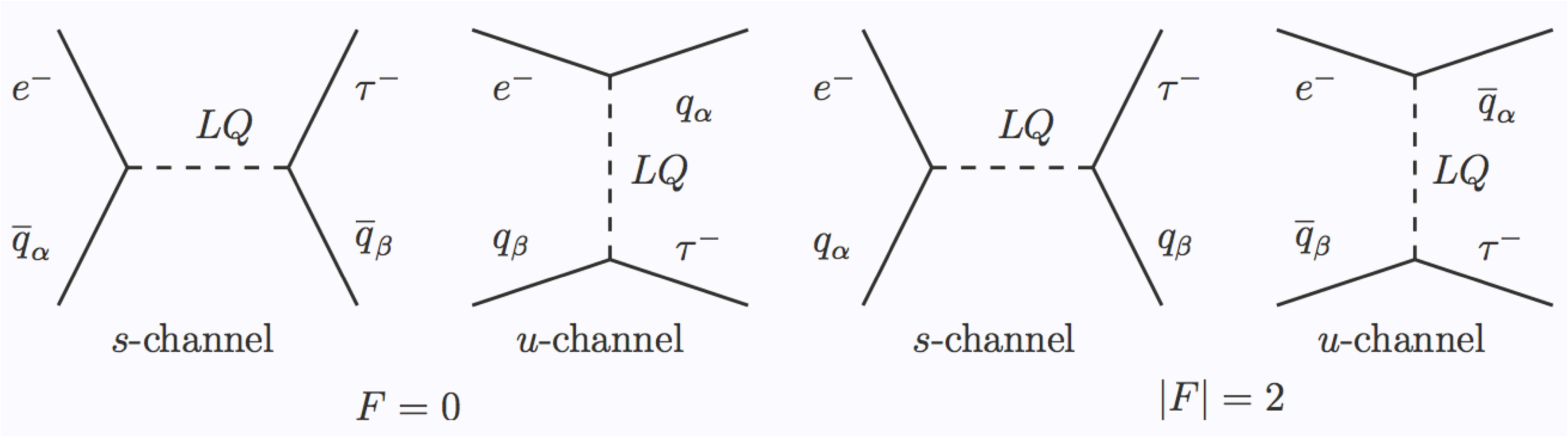
Weak mixing angle

- Points aren't individually competitive
- BUT can scan $\sin^2\theta_W$ over a wide range of Q^2



Demanding on
- Polarimetry
- Luminosity

τ-e conversion



- Neutrino oscillation → lepton flavour not conserved
  - Is there ***charged*** lepton flavour violation? e.g. via leptoquarks
  - Low-energy probe of early universe physics

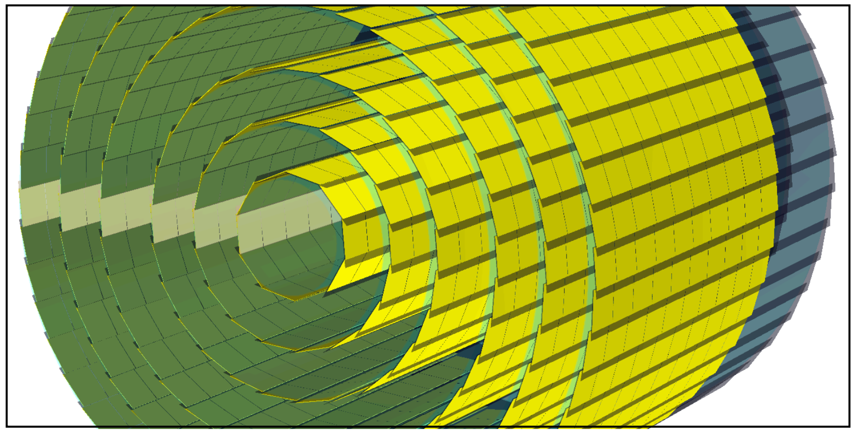
arXiv: 1006.5063

- 1st and 2nd generation coupling well-studied
  - **1st-to-3rd** has much weaker limits (BaBar, BELLE)
  - Concentrate on $\mathbf{e + p \rightarrow \tau + X}$
  - EIC luminosity → surpass HERA limits on coupling/mass ratios

τ-e conversion

- Must separate background DIS τ from leptoquark decay τ
  - via decay topology: high p_T e, μ back-to-back to hadron system
  - vertex detector for (200-3,000)μm-displaced τ vertex
- **Intriguing probe** of new physics, but needs **further study** to account for detector efficiency etc to more accurately assess feasibility
  - but potentially competitive with B-factories (BELLE, BaBar)
- Pushes EIC demands on
  - luminosity: 100-200 fb^{-1}
  - detector performance

Vertex detector



Conclusion

- TBD